PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No.:	09/784,829
Filing Date:	February 8, 2001
Applicants:	Jean Francois Uhl et al.
Group Art Unit:	3737
Examiner:	Ruth S. Smith
Title:	INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHOMOGENEOUS STRUCTURE
Attorney Docket:	5074A-000013/REA

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

STATEMENT OF FACTS

ACCOMPANYING A PETITION UNDER 37 CFR 1.47(B) TO ACCEPT AN UNSIGNED SUPPLEMENTAL REISSUE DECLARATION BASED ON A REFUSAL OF ALL OF THE INVENTORS

Sir:

1. I, Michael L. Taylor, Reg. No. 50,521 make the following "Statement of Facts" regarding communications and refusals of the inventors of U.S. Pat. App. No. 09/784,829, which is a reissue application of U.S. Patent 5,568,675, to sign and return for filing with the U.S. Patent and Trademark Office a Supplemental Reissue Declaration.

2. On August 29, 2011, I sent an email to inventor Michel Scriban requesting a time to speak with him via telephone regarding the subject reissue application 09/784,829 in which he is a co-inventor with Joel Henrion, Jean Francois Uhl, and Jean-Baptiste Thiebeaut. After the initial email on August 29, 2011 (*See*, Attachment A), I had a brief telephone conversation, in the English language, with Michel Scriban on August 30, 2011 to discuss the requirement for a Supplemental Reissue Declaration and the best way to send the necessary papers to Michel Scriban and all of his co-inventors.

3. On August 31, 2011, I sent a first email communication with papers for review to the last known email addresses for Michel Scriban, Joel Henrion, and Jean Francois Uhl. In this first email I also requested that Michel Scriban contact Jean-Baptiste Thiebeaut. In this first email I included a Supplemental Reissue Declaration in both French and English languages, the U.S. Patent 5,568,675 for which the reissue is being requested, and the currently pending claims. *See*, Attachment B. This first email sent on August 31, 2011 was sent in English and French for convenience of the inventors who we believed were domiciled in France. An English original of the French Language portion of the email is included under Attachment C.

4. Included under Attachments D-F (where Attachment F includes an English translation of the original French communication under Attachment E) are various communications between Michel Scriban and myself during the month of September 2011.

5. Following the communications between Michel Scriban and myself in September 2011, Michel Scriban made a first demand in an email to me on October 9,

2011 for payment of 70,800 EUROS (about US$95,500) to be paid to all of the inventors for their review of the papers sent in my first email of August 31, 2011 and to execute the Supplemental Reissue Declaration. *See*, Attachment G. An English language translation of the letter under Attachment Tab G is provided under Attachment H.

6. In response to Michel Scriban's October 9, 2011 email (Attachment G), Richard W. Warner, Reg. No. 38,043 and I prepared a detailed letter, sent on November 1, 2011, setting out the current Assignee's position that no further payments were required and that such a demand of payment to review and execute the Supplemental Reissue Declaration amounted to a refusal to sign. The November 1, 2011 letter was sent both via email to each of the inventors and via DHL courier service. *See*, Attachment I. The November 1 letter included attachments of the original Assignment from each of the inventors to Daidix S.A. that indicated that further remuneration was not necessary to assist in obtaining reissues of the original application. Further, we included the Assignment recordal chain from the www.uspto.gov website indicating assignments of the U.S. Patent 5,568,675 to Medtronic, Inc. Additionally, we included a paper copy of the Supplemental Reissue Declaration, both in English and French, the originally issued U.S. Patent 5,868,675 of which this is a reissue application, and the claims as currently pending.

7. We received confirmation from DHL that the package was delivered to and accepted at each of the addresses that we had for all four of the named inventors of the U.S. Patent 5,868,675. I sent an email to each of the inventors noting that we had confirmation from DHL, including a copy of the confirmations, that each of the inventors had received the package. *See*, Attachment J. Joel Henrion indicated that the package

was not sent to his proper address and that he did not receive it. However, Joel Henrion communicated this in an email (*See*, Attachment K) that originated from the email address to which I also sent the same package of information (including the Supplemental Reissue Declaration, the originally issued U.S. Patent 5,568,675, and the currently pending claims). Accordingly, I believe that Joel Henrion did receive an email communication that included all of the same papers that were sent via the DHL courier to the address I had for Joel Henrion. Prior to resending a paper copy to Joel Henrion, I was notified that an attorney Maxime Grange in France now represents all of the inventors and that the attorney has also received the communication sent on November 1, 2011 that included the Supplemental Reissue Declaration, the issued U.S. Patent 5,568,675, and the claims as pending. *See*, Attachment L.

8. We requested in our letter of November 1, that each of the inventors execute and return to Richard W. Warner (or myself) the Supplemental Reissue Declaration by November 14, 2011. We provided this extended time for reply even though each of the inventors had previously been forwarded the package, at least as early as August 31st, either directly by me or through Michel Scriban. Nevertheless, on November 15, 2011, I received an email from attorney Maxime Grange indicating that the inventors did not intend to sign the Supplemental Reissue Declaration and that, in addition to the previously requested monies, an additional 4200 EUROS (about US$5600) was required for his services in setting up of an escrow account to receive the previously demanded 70,800 EUROS (about US$95,500). *See*, Attachment L. An English translation of the letter from Attorney Grange is provided under Attachment M.

9. I responded to attorney Maxime Grange's letter on November 23, 2011 by email including a request to confirm that attorney Maxime Grange was an attorney for all of the inventors Michel Scriban, Joel Henrion, Jean Francois Uhl, and Jean-Baptiste Thiebeaut. I additionally forwarded to attorney Grange my November 1, 2011 letter originally sent to all of the inventors that included the Supplemental Reissue Declaration, a copy of the US Patent 5,868,675, a copy of the claims as currently pending, the assignment chain from www.uspto.gov, and the assignment from all of the inventors to Daidix S.A. *See*, Attachment N.

10. Finally, on November 29, 2011, I received an email from attorney Grange following up to my email of November 23, stating that attorney Grange had received my correspondences to which he was replying in the email. He further states that he represents the French experts and that they cannot study the documents that we provided and it is not possible to sign them. *See*, Attachment O, an English Translation of the email is under Attachment P.

Respectfully submitted,

Dated: Dec. 21, 2011

By: ______________________
Michael L. Taylor
Reg. No. 50,521

HARNESS, DICKEY & PIERCE, P.L.C.
P.O. Box 828
Bloomfield Hills, Michigan 48303
(248) 641-1600

RWW/MLT/srh
16429102.1

ATTACHMENT A

Taylor, Michael

From: Taylor, Michael <mltaylor@HDP.com>
Sent: Monday, August 29, 2011 3:21 PM
To: m.scriban@nelixa.fr
Cc: Warner, Rick
Subject: Re-issue of U.S. Patent 5,568,675 (5074a-000013/REA)

Dear Dr. Scriban,

You may recall in late 2002 you communicated with Richard Warner regarding the above referenced U.S. Patent.

We are nearing the end of prosecution, and I was wondering if I could call you tomorrow at 33-4-72-71-01-39 at about 2:30PM Paris time regarding contact information for you and your co-inventors Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut.

Thank you,

Michael

Michael L. Taylor
Patent Attorney

Office: 248.641.1600
Direct: 248.641.1289
Fax: 248.641.0270

HARNESS DICKEY
IP Causes Worldwide

5445 Corporate Dr, Suite 200
Troy, MI 48098
Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

ATTACHMENT B

Taylor, Michael

From: Taylor, Michael <mltaylor@HDP.com>
Sent: Wednesday, August 31, 2011 3:06 PM
To: m.scriban@nelixa.fr
Cc: Joel.henrion@wanadoo.fr; Jf.uhl@free.fr; Jf.uhl@wanadoo.fr; Warner, Rick; Neal, Patrick; Hall, Stephanie
Subject: Re-issue of U.S. Patent 5,568,675 (5074a-000013/REA)
Attachments: Supplemental Reissue declaration.PDF; US 5868675.PDF; Current Claims.DOC

Dr. Scriban,

As we discussed yesterday, I am forwarding this email that discusses the U.S. Patent Application that is a reissue of the above referenced U.S. Patent and papers that we need executed. I am also copying each inventor for which we previously had an email address, Joel Henrion and Joel Francois Uhl. You indicated that you would forward this email to Jean-Baptiste Thiebaut, and also to Joel Henrion and Joel Francois Uhl if the email addresses we have for them are no longer correct. We previously had translated the below message that discusses the current process and our reason for contacting you. Also, if you have an email address for Jean-Baptiste Thiebaut, we would very much appreciate receiving it from you.

We very much appreciate your assistance in this matter. Please let us know any one of you will not be able to return the executed paper to us by October 3, 2011.

Comme vous pouvez vous en souvenir, vous avez été en contact avec Rick Warner ou Christopher Eusebi fin 2002 et début 2003 concernant une demande de redélivrance du brevet U.S. 5 568 675 (ci-joint). À ce moment-là, vous aviez exécuté une déclaration de redélivrance.

Lors de votre travail avec le bureau des brevets U.S. pour obtenir un brevet subventionnable, nous avons amendé les réclamations par celles jointes dans les « réclamations actuelles » ci-jointes, que nous vous soumettons pour révision. Selon les règles régissant les demandes de redélivrance, nous allons déposer une déclaration de redélivrance additionnelle. Nous avons joint une « déclaration de redélivrance additionnelle » pour votre exécution. Nous pensons qu'il s'agit du dernier document nécessaire pour cette demande. Une fois que le bureau des brevets U.S. reçoit ce document dûment exécuté, une redélivrance de brevet devrait être accordée. Un brevet redelivré remplace essentiellement le brevet d'origine.

Veuillez dûment exécuter la « déclaration de redélivrance additionnelle » et nous la renvoyer. Vous pouvez nous l'envoyer par courriel ou par fax. Si vous ne pouvez nous envoyer pas courriel ou par fax une copie dûment exécutée et devez envoyer une copie physique, nous pouvons vous donner un numéro de compte DHL pour couvrir le coût de l'envoi.

Dans le tableau ci-dessous, vous trouverez les coordonnées que nous avons pour chacun des inventeurs. Veuillez confirmer que ces informations sont exactes. Si vous pouviez également nous donner l'adresse courriel de Jean-Baptiste Thiebaut, nous en serions très reconnaissants.

Nous vous remercions d'avance pour votre aide et votre réponse rapide.

Name	DHL/Mailing Address	Email Address(es)	Phone
Michel Scriban	72 Chemin de Crapon 69360 Ternay, France	m.scriban@nelixa.fr	
Joel Henrion	17, Route de Chalone 51600 Suippes, France	Joel.henrion@wanadoo.fr	
Jean Francois UHL	199 avenue du Maine Paris, France 75014 *(auxiliary address- 12 rue Regard; 92380 Garche, France)*	Jf.uhl@free.fr Jf.uhl@wanadoo.fr	
Jean-Baptiste Thiebaut	42 boulevard Saint-Marcel Paris, France 75005		

Thank you and Best Regards,

Michael

Michael L. Taylor
Patent Attorney

Office: 248.641.1600
Direct: 248.641.1289
Fax: 248.641.0270

HARNESS DICKEY
IP Causes Worldwide

5445 Corporate Dr, Suite 200
Troy, MI 48098
Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

English	French
SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)	DÉCLARATON SUPPLÉMENTAIRE POUR REDÉLIVRANCE D'UNE DEMNADE DE BREVET POUR CORRIGER DES « ERREURS » (37 CFR 1.175)
Attorney Docket: 5074A-000013/REA First Named Inventor: Jean Francois Uhl Application Number: 09/784,829 Filing Date: February 8, 2001 Art Unit: 3737 Examiner Name: Ruth S. Smith	Numéro de registre: 5074A-000013/REA Nom du premier inventeur: Jean Francois Uhl Numéro de l'application: 09/784,829 Date de dépôt: 8 février 2001 Unité d'art : 3737 Nom de l'examinateur: Ruth S. Smith
I/We hereby declare that: Every error in the patent which was corrected in the present reissue application, and which is not covered by the prior oath(s) and/or declaration(s) submitted in this application, arose without any deceptive intention on the part of the applicant. WARNING: Petitioner/applicant is cautioned to avoid submitting personal information in documents files in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/application is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available. I/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.	Je(nous) déclare(ons) que : Toute erreur dans le brevet qui a été corrigée dans cette demande de redélivrance et qui n'est pas couverte par le présent serment ou déclaration soumis à cette demande, s'est produite sans intention de tromper de la part de l'appliquant. AVERTISSEMENT : Le requérant / demandeur est mis en garde contre la soumission de renseignements personnels dans les documents déposés dans une demande de brevet qui peuvent aider à l'usurpation d'identité. Les renseignements personnels tels que numéros de sécurité sociale, numéros de compte bancaire, ou numéros de carte de crédit (autre qu'un chèque ou un formulaire d'autorisation de carte de crédit PTO-2038 dans le but de faire un paiement) ne sont jamais requis par l'USPTO (Bureau des brevets des États-Unis) pour appuyer une pétition ou une demande. Si ce type de renseignements personnels est inclus dans les documents déposés à l'USPTO, les demandeurs / requérants devraient envisager de les enlever des documents avant de les soumettre à l'USPTO. Le requérant / demandeur est informé que le dossier de demande de brevet est à la disposition du public après la publication de la demande (sauf si une demande de non-publication en conformité avec 37 CFR 1.213 (a) a été faite dans cette demande) ou après la délivrance d'un brevet. En outre, le dossier d'une demande abandonnée peut également être mis à la disposition du public si la demande est référencée dans une application publiée ou un brevet délivré (voir 37 CFR 1.14). Les chèques et formulaires d'autorisation de carte de crédit PTO-2038 soumis pour fins de paiement ne sont pas conservés dans le dossier de demande et ne sont donc pas accessibles au public. Je / Nous déclarons que toutes les déclarations faites selon ma/notre connaissance dans ce document sont véridiques et que toutes les déclarations faites sur des informations et croyances sont considérées comme vraies. De plus, ces déclarations ont été faites en sachant que toute fausse déclaration volontaire est passible d'une amende ou d'une peine d'emprisonnement, ou les deux, en vertu de la loi 18 USC 1001 et que de telles déclarations risquent de compromettre la validité de la demande ou d'un brevet délivré à partir de celle-ci.
Name of First Inventor: Jean Francois Uhl Inventor's Signature ________________ Date _________________	Nom du premier inventeur: Jean Francois Uhl Signature de l'inventeur ________________ Date ____________________
Name of Second Inventor: Joel Henrion Inventor's Signature________________ Date________________	Nom du deuxième inventeur : Joel Henrion Signature de l'inventeur ________________ Date ____________________
Name of Third Inventor: Michel Scriban Inventor's Signature ________________ Date ________________	Nom du troisième inventeur : Michel Scriban Signature de l'inventeur ________________ Date ____________________
Name of Fourth Inventor: Jean-Baptiste Thiebaut Inventor's Signature ________________ Date________________	Nom du quatrième inventeur : Jean-Baptiste Thiebaut Signature de l'inventeur ________________ Date ____________________

US005868675A

United States Patent [19]

Henrion et al.

[11] **Patent Number: 5,868,675**

[45] **Date of Patent: *Feb. 9, 1999**

[54] **INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE**

[75] Inventors: **Joël Henrion**, Suippes; **Michel Scriban**, Ternay; **Jean-Baptiste Thiebaut**; **Jean-François Uhl**, both of Paris, all of France

[73] Assignee: **Elekta IGS S.A.**, Gieres, France

[*] Notice: The terminal 36 months of this patent has been disclaimed.

[21] Appl. No.: **847,059**

[22] PCT Filed: **May 10, 1990**

[86] PCT No.: **PCT/FR90/00714**

§ 371 Date: **Jun. 22, 1992**

§ 102(e) Date: **Jun. 22, 1992**

[87] PCT Pub. No.: **WO91/04710**

PCT Pub. Date: **Apr. 18, 1991**

[30] **Foreign Application Priority Data**

Oct. 5, 1989 [FR] France 89 13028

[51] **Int. Cl.**[6] **A61B 5/05**

[52] **U.S. Cl.** **600/424**; 606/130

[58] **Field of Search** 128/653.1; 378/4, 378/20, 41, 58, 205; 606/130; 901/6, 16, 41; 600/407, 411, 415, 417, 424

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,638,798	1/1987	Shelden et al.	606/130
4,791,934	12/1988	Brunnett	128/653.1
5,050,608	9/1991	Watanabe et al.	128/653.1
5,078,140	1/1992	Kwoh	128/653.1
5,143,076	9/1992	Hardy et al.	606/130
5,186,174	2/1993	Schlöndorff et al.	128/653.1
5,273,039	12/1993	Fujiwara et al.	600/407
5,280,427	1/1994	Magnusson et al.	606/130
5,285,787	2/1994	Machida	606/130
5,409,497	4/1995	Siczek et al.	606/130
5,572,999	11/1996	Fubda et al.	600/407

FOREIGN PATENT DOCUMENTS

0009151	12/1988	WIPO .
WO 88/09151	12/1988	WIPO .

OTHER PUBLICATIONS

Lavallee, S. A New System for Computer Assisted Neurosurgery. IEEE Engineering in Medicine & Biology Society 11th Annual International Conference, vol. 11, pp. 926–927, Nov. 1989.

Watanabe, E et al. Three–Dimenstional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotaxic Surgery. Surg. Neurol., vol. 27, pp. 543–547, 1987.

(List continued on next page.)

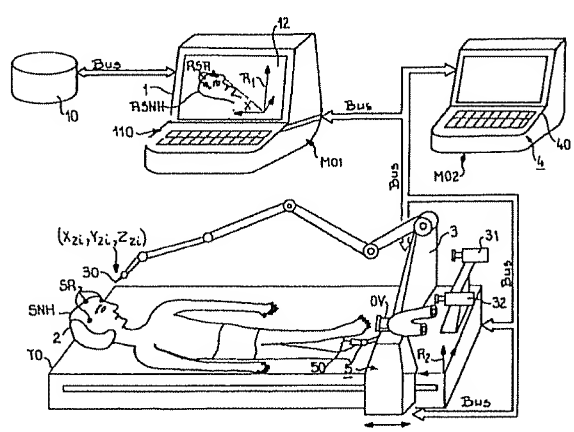
Primary Examiner—Brian Casler

Attorney, Agent, or Firm—Blakely Sokoloff Taylor & Zafman

[57] **ABSTRACT**

An interactive system for a local intervention inside a region of a non-homogeneous structure, such as the skull of a patient, which is related to the frame of reference (R_2) of an operation table, and which is connected to a reference structure comprising a plurality of base points. The system creates on a screen a representation of the non-homogeneous structure and of the reference structure connected thereto, provides the coordinates of the images of the base points in the first frame of reference (R_1), allows the marking of the coordinates of the base points in R_2, and allows the carrying out of the local intervention with an active member such as a trephining tool, a needle, or a radioactive or chemical implant. The systems also optimizes the transfer of reference frames between R_1 and R_2, from the coordinates of the base points in R_2 and the images in R_1 by reducing down to a minimum the deviations between the coordinates of images in R_1 and the base points in R_1 after transfer. The system also establishes real time bi-directional coupling between: (1) an origin and a direction of intervention simulated on the screen, (2) the position of the active member.

16 Claims, 13 Drawing Sheets



OTHER PUBLICATIONS

Batnitzky, S. et al. Three–Dimensional Computer Reconstruction from Surface Contours for Head CT Examinations. J. Comp. Asst. Tomogr., vol. 5, No. 1, pp. 60–67, Feb. 1981.

Roberts, D.W., et al. A Frameless Stereotaxic Integration of Computerized Tomographic Imaging and the Operating Microscope. J. Neurosurg., vol. 65, pp. 545–549, 1986.

Kelly, P.J. et al. Computer–assisted Stereotactic Laser Microsurgery for the Treatment of Intracranial Neoplasms, Neurosurgery. vol. 10, No. 3, pp. 324–330, 1982.

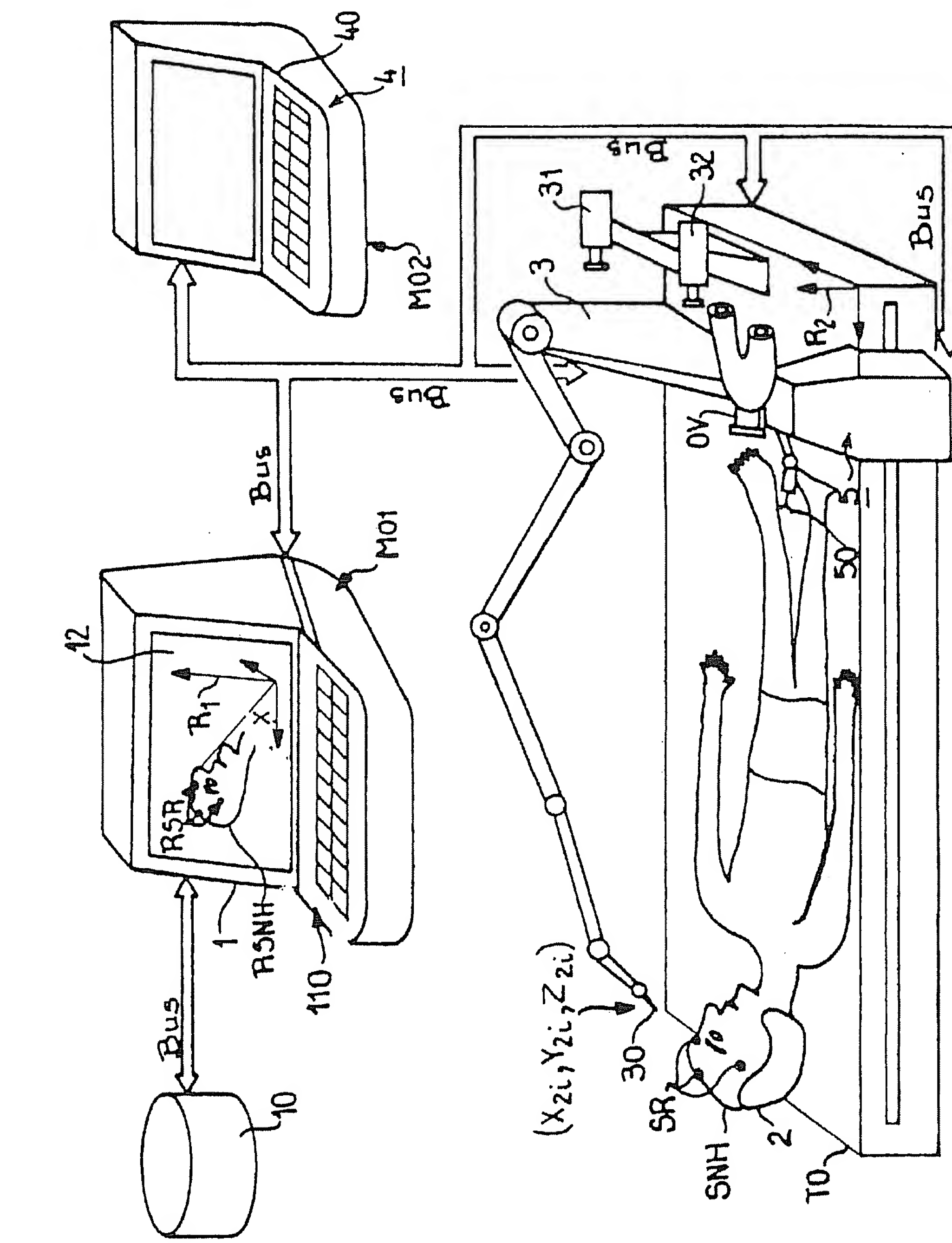
S. Lavallee, "A New System for Computer Neurosurgery", IEEE Eng. in Medicine & Bio. Soc. 11th Annual Int. Conf., Nov. 9–12, 1989, pp. 926–927.

Watanabe et al., Three Dimensional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotoxic Surgery, Surg. Neurol., 1987, No. 27, pp. 543–547.

P.J. Kelly et al., "Computer–Assisted Stereotactic Laser Micro–Surgery for the Treatment of Intracranial Neoplasms", Neuro., vol. 10, No. 3, 1982, pp. 324–330.

Batnitzky et al., "Three–dimensional Computer Reconstruction From Surface Contours for Head CT Examinations", Journal of Comp. Assisted Tomography, No. 5, Feb. 1981, pp. 60–67

Roberts et al., "A Frameless Stereotoxic Integration of Computerized Tomographic Imaging and the Operating Microsc gsl", J. of Neuro. Surg. No. 65, 1986, pp. 545–549.



40
4
M02
Bus
31
32
3
R2
OV
5
50
12
R1
X
RSR
RSNH
1
110
M01
Bus
10
(X2i, Y2i, Z2i)
30
SR
SNH
2
T0

FIG. 1

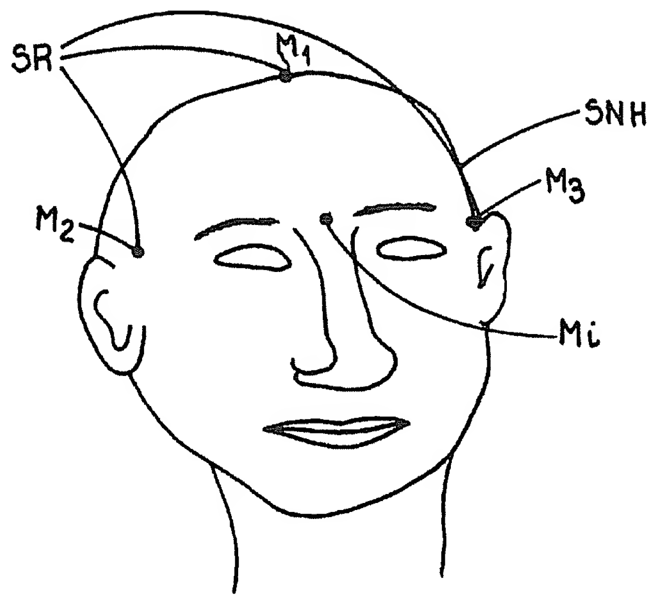


FIG_2

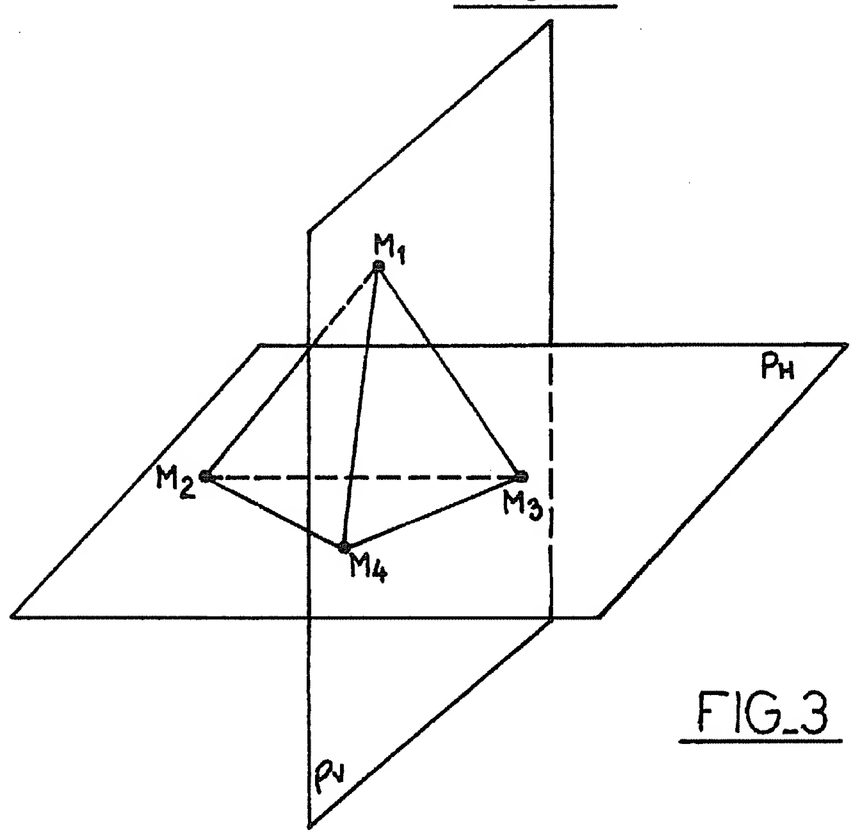


FIG_3

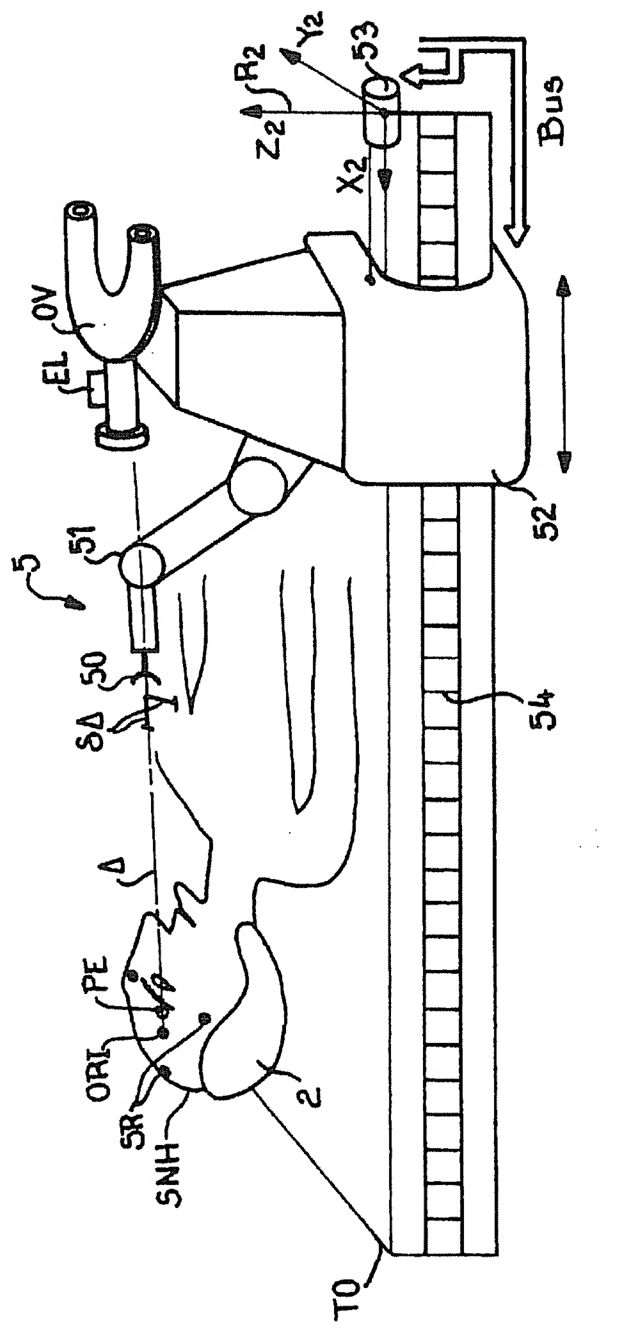


FIG_4

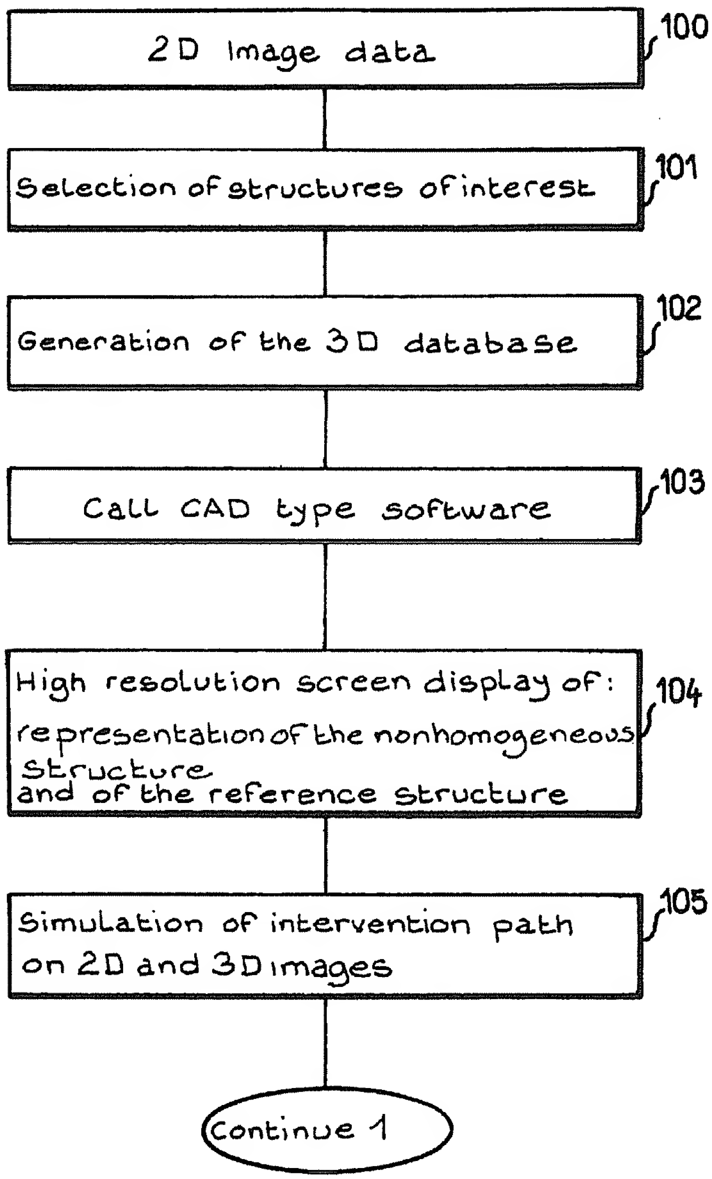

2D Image data
100
Selection of structures of interest
101
Generation of the 3D database
102
Call CAD type software
103
High resolution screen display of:
representation of the nonhomogeneous structure
and of the reference structure
104
Simulation of intervention path
on 2D and 3D images
105
Continue 1

FIG_5a

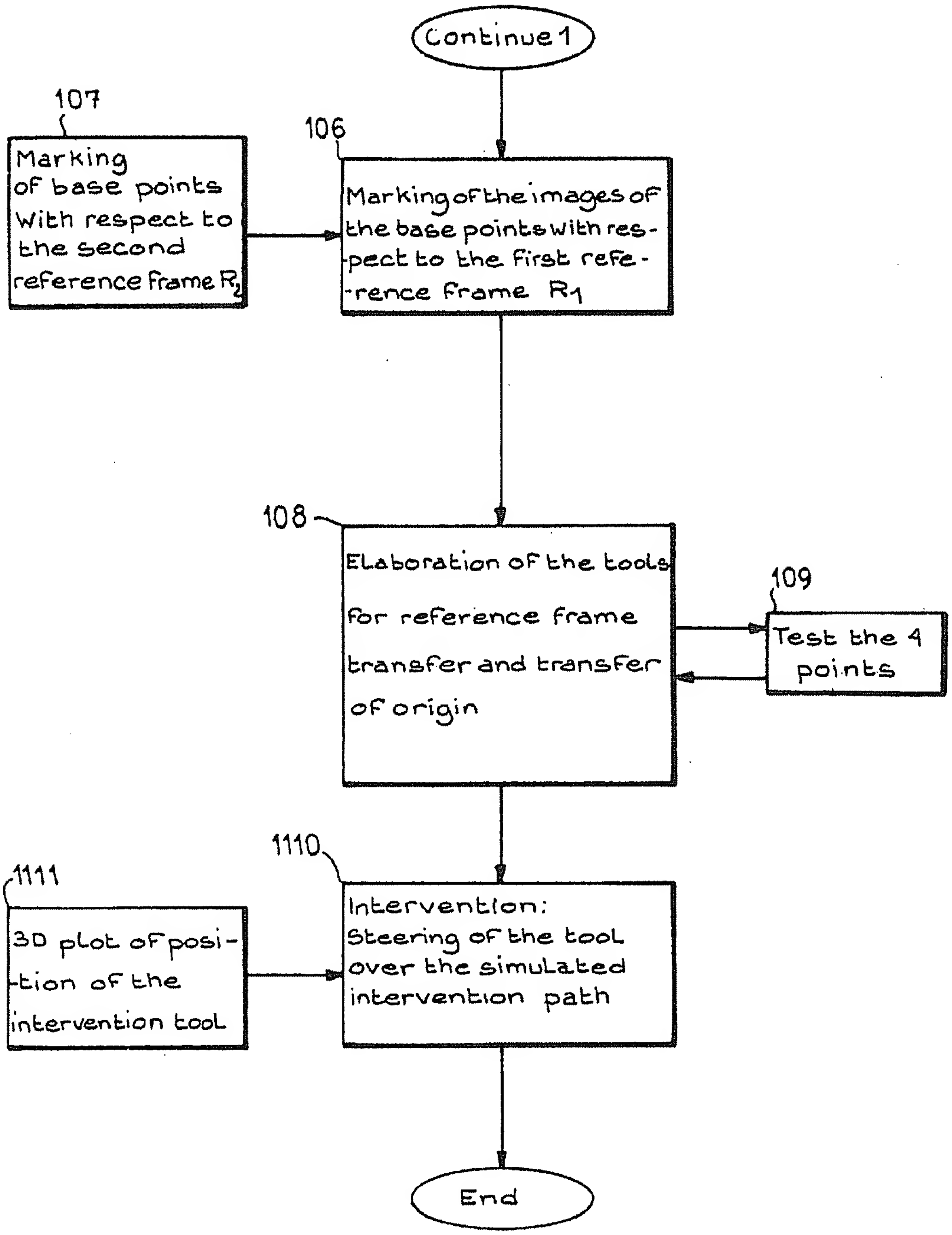

Continue 1
107
Marking of base points with respect to the second reference frame R_2
106
Marking of the images of the base points with respect to the first reference frame R_1
108
Elaboration of the tools for reference frame transfer and transfer of origin
109
Test the 4 points
1111
3D plot of position of the intervention tool
1110
Intervention: Steering of the tool over the simulated intervention path
End

FIG_5b

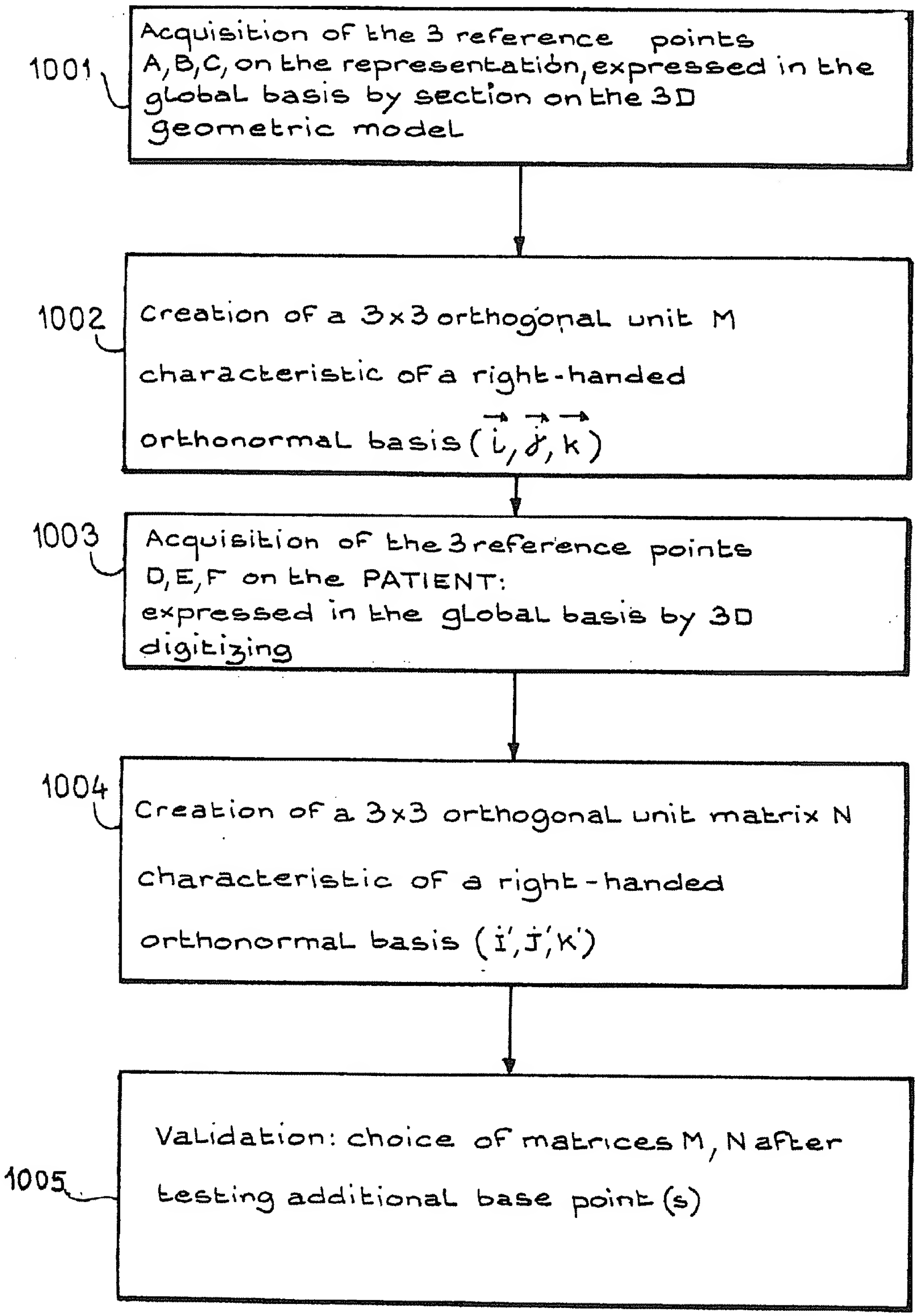

1001
Acquisition of the 3 reference points A,B,C, on the representation, expressed in the global basis by section on the 3D geometric model
1002
Creation of a 3x3 orthogonal unit M characteristic of a right-handed orthonormal basis $(\vec{i}, \vec{j}, \vec{k})$
1003
Acquisition of the 3 reference points D,E,F on the PATIENT: expressed in the global basis by 3D digitizing
1004
Creation of a 3x3 orthogonal unit matrix N characteristic of a right-handed orthonormal basis (i',j',k')
1005
Validation: choice of matrices M, N after testing additional base point (s)

FIG 6

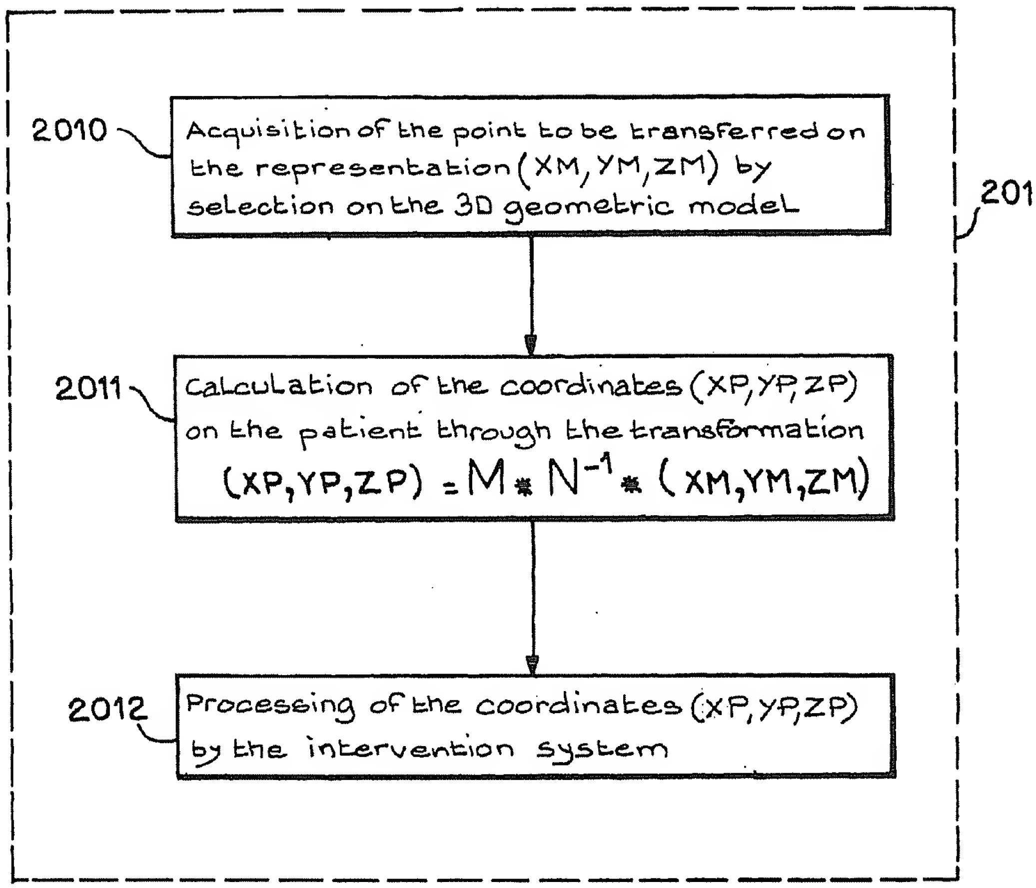

2010
Acquisition of the point to be transferred on the representation (XM, YM, ZM) by selection on the 3D geometric model
201
2011
Calculation of the coordinates (XP, YP, ZP) on the patient through the transformation
(XP, YP, ZP) = M * N^-1 * (XM, YM, ZM)
2012
Processing of the coordinates (XP, YP, ZP) by the intervention system

FIG_7

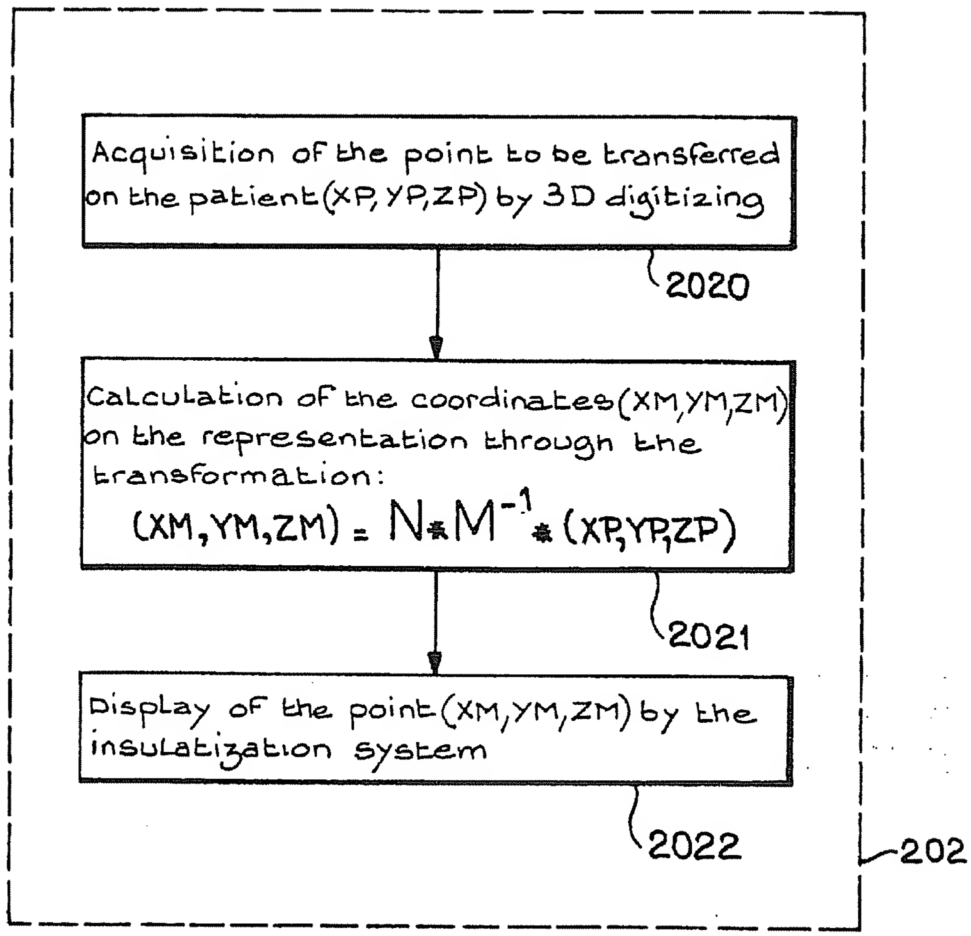

Acquisition of the point to be transferred on the patient (XP, YP, ZP) by 3D digitizing
2020
Calculation of the coordinates (XM, YM, ZM) on the representation through the transformation:
(XM, YM, ZM) = N * M^-1 * (XP, YP, ZP)
2021
Display of the point (XM, YM, ZM) by the insulatization system
2022
202

FIG_8

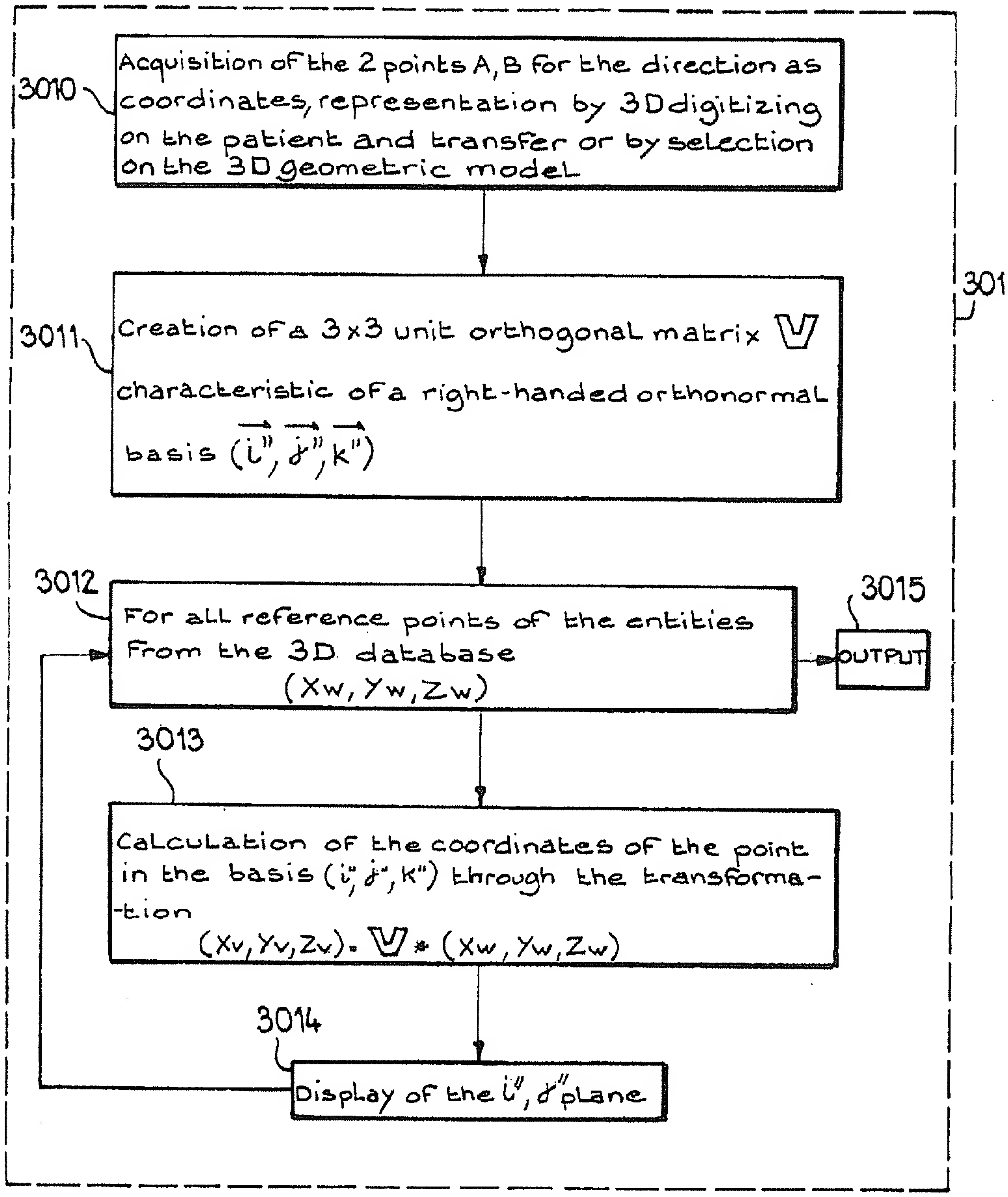

Acquisition of the 2 points A, B for the direction as coordinates, representation by 3D digitizing on the patient and transfer or by selection on the 3D geometric model
3010
Creation of a 3x3 unit orthogonal matrix V characteristic of a right-handed orthonormal basis ($\vec{i''}$, $\vec{j''}$, $\vec{k''}$)
3011
301
3012
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3015
OUTPUT
3013
Calculation of the coordinates of the point in the basis (i'', j'', k'') through the transformation (Xv, Yv, Zv) = V * (Xw, Yw, Zw)
3014
Display of the i'', j'' plane

FIG_9a

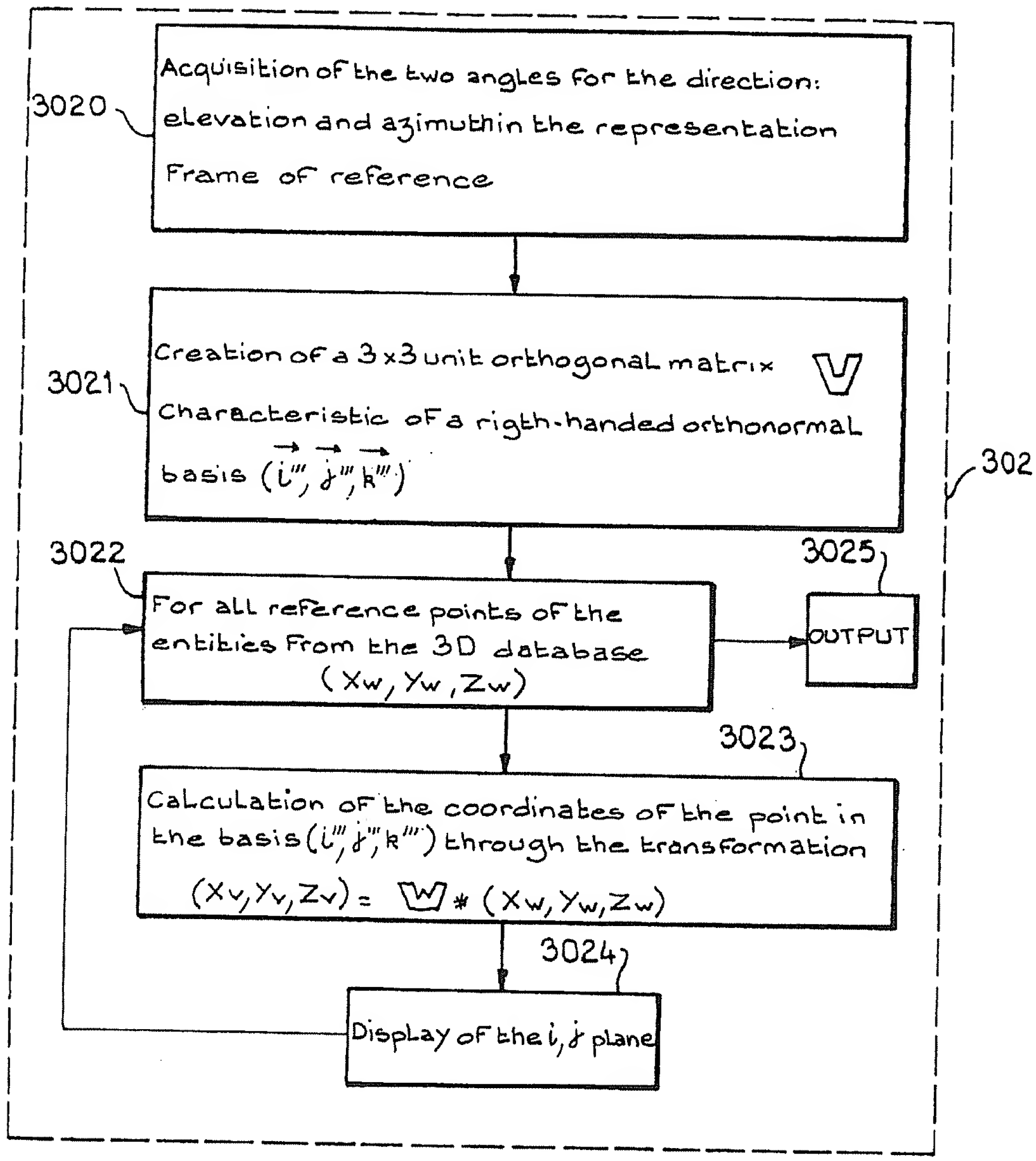

3020
Acquisition of the two angles for the direction: elevation and azimuth in the representation frame of reference
3021
Creation of a 3x3 unit orthogonal matrix V characteristic of a rigth-handed orthonormal basis ($\vec{i}'''$, $\vec{j}'''$, $\vec{k}'''$)
302
3022
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3025
OUTPUT
3023
Calculation of the coordinates of the point in the basis (i''', j''', k''') through the transformation (Xv, Yv, Zv) = W * (Xw, Yw, Zw)
3024
Display of the i, j plane

FIG_9b

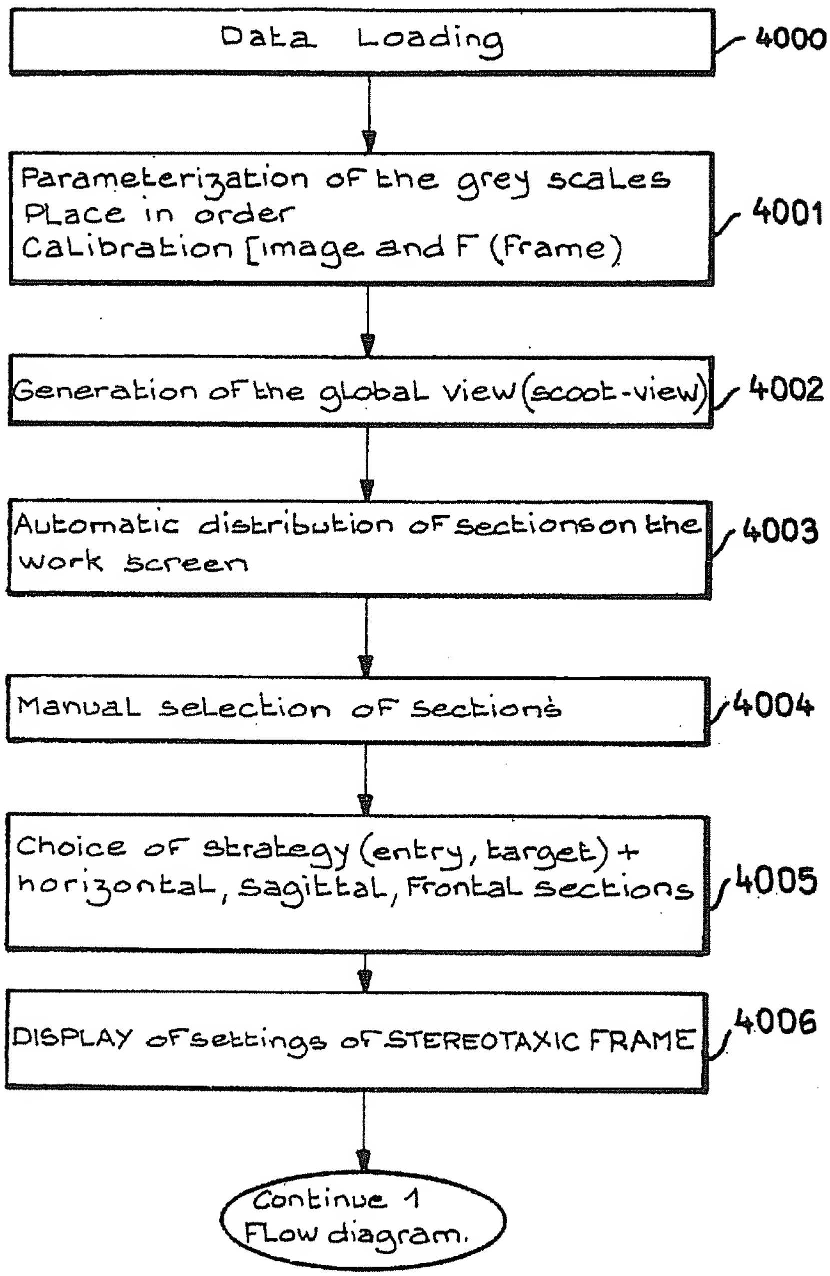

Data Loading
4000
Parameterization of the grey scales
Place in order
Calibration [image and F (Frame)
4001
Generation of the global view (scoot-view)
4002
Automatic distribution of sections on the work screen
4003
Manual selection of sections
4004
Choice of strategy (entry, target) + horizontal, sagittal, frontal sections
4005
DISPLAY of settings of STEREOTAXIC FRAME
4006
Continue 1
Flow diagram.

FIG_10a

FIG_10b

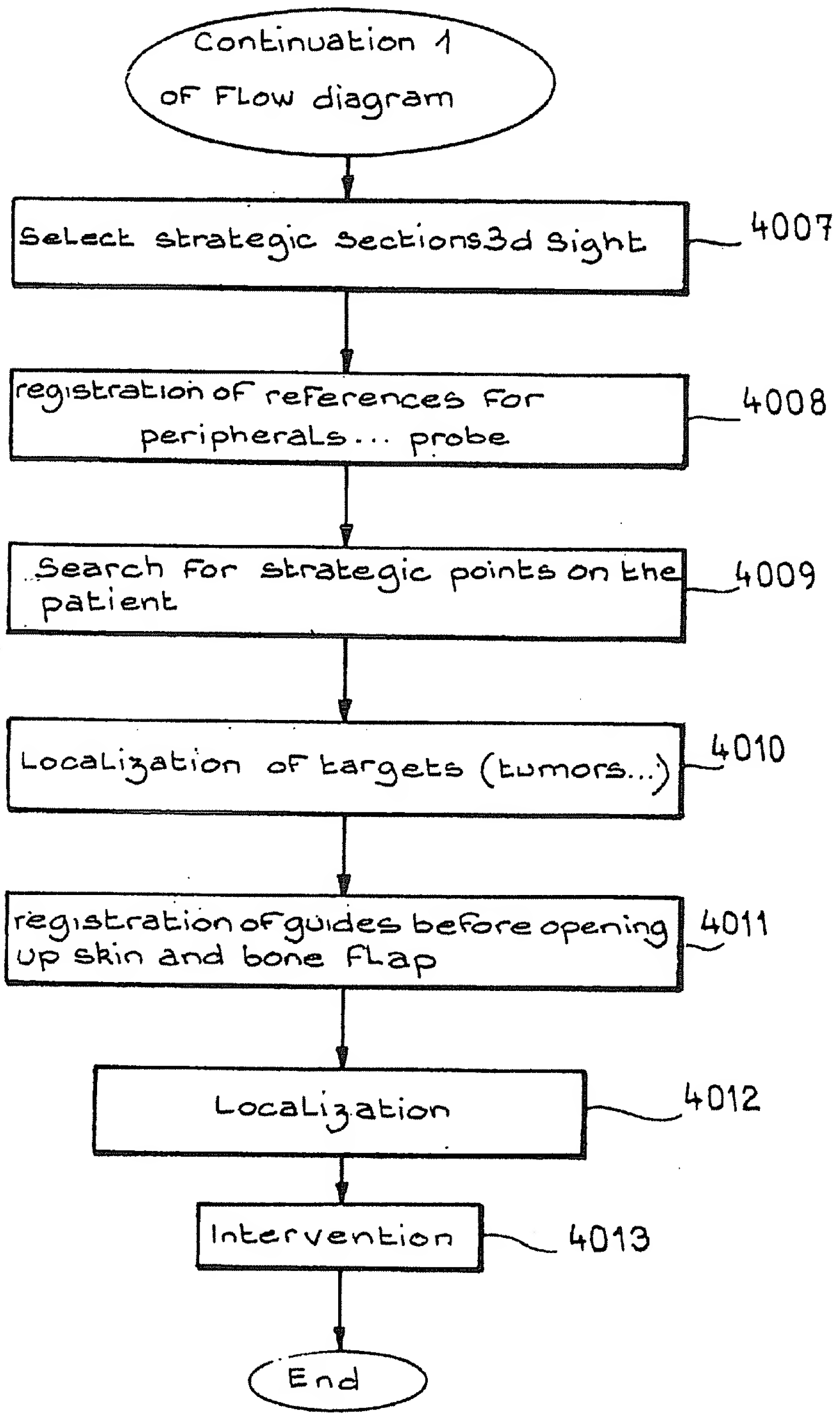
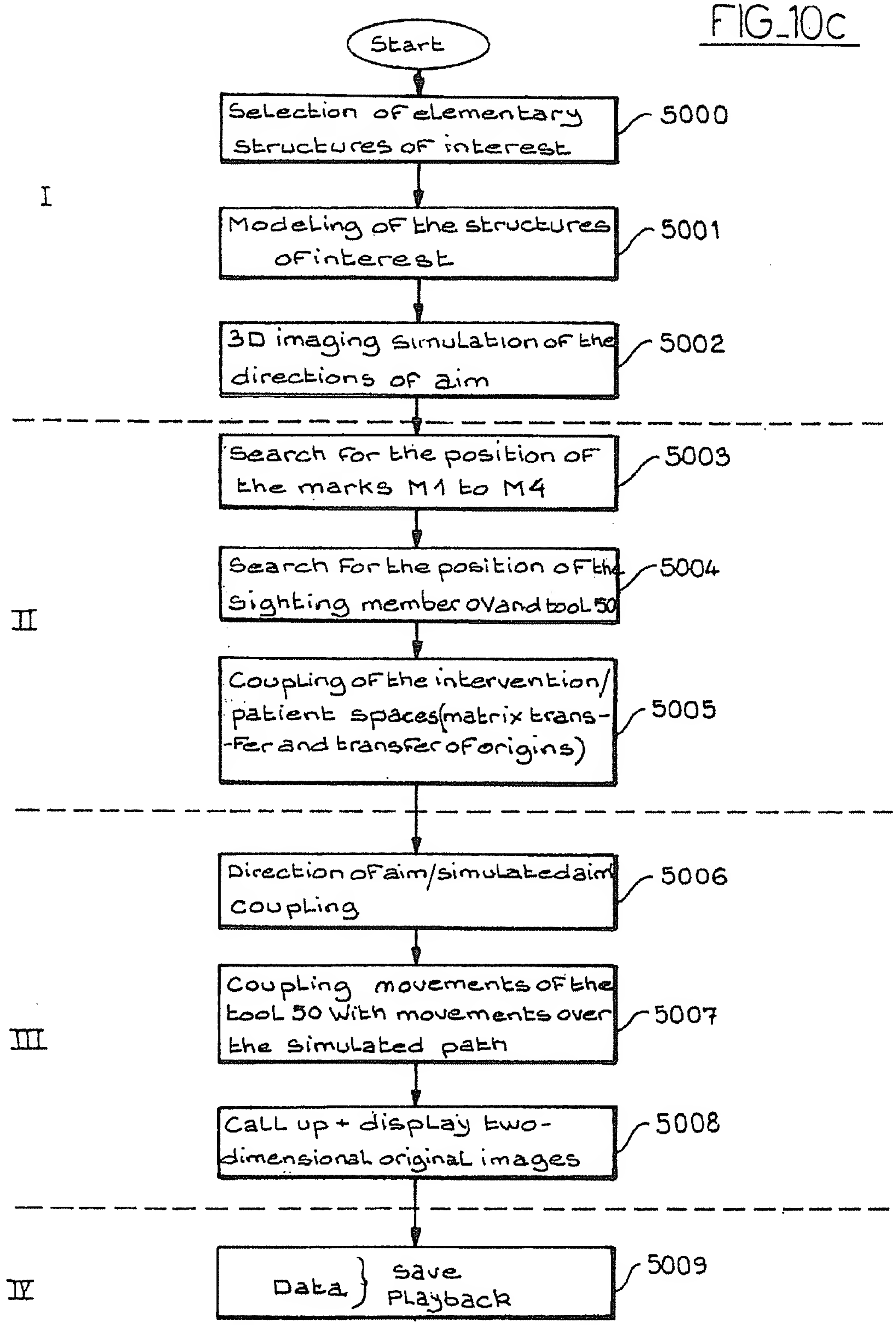

Continuation 1
of Flow diagram
Select strategic sections3d sight
4007
registration of references for peripherals... probe
4008
Search for strategic points on the patient
4009
Localization of targets (tumors...)
4010
registration of guides before opening up skin and bone flap
4011
Localization
4012
Intervention
4013
End

FIG_10c


Start
Selection of elementary structures of interest
5000
Modeling of the structures of interest
5001
3D imaging simulation of the directions of aim
5002
I
Search for the position of the marks M1 to M4
5003
Search for the position of the sighting member OV and tool 50
5004
Coupling of the intervention/patient spaces (matrix trans-fer and transfer of origins)
5005
II
Direction of aim/simulated aim coupling
5006
Coupling movements of the tool 50 with movements over the simulated path
5007
Call up + display two-dimensional original images
5008
III
Data } save playback
5009
IV

INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE

The invention relates to an interactive system for local intervention inside a region of a nonhomogeneous structure.

The performing of local interventions inside a nonhomogeneous structure, such as intracranial surgical operations or orthopedic surgery currently poses the problem of optimizing the intervention path or paths so as to secure, on the one hand, total intervention over the region or structure of interest, such as a tumor to be treated or explored and, on the other hand, minimal lesion to the regions neighboring or adjoining the region of interest, this entailing the localizing and then the selecting of the regions of the nonhomogeneous structure which are least sensitive to being traversed or the least susceptible to damage as regards the integrity of the structure.

Numerous works aimed at providing a solution to the abovementioned problem have hitherto been the subject of publications. Among the latter may be cited the article entitled "Three Dimensional Digitizer (Neuronavigator): New Equipment for computed Tomography Guided Stereotaxic Surgery", published by Eiju Watanabe, M.D., Takashi Watanabe, M.D., Shinya Manaka, M.D., Yoshiaki Mayanagi, M.D., and Kintomo Takakura, M.D. Department of Neurosurgery, Faculty of Medicine, University of Tokyo, Japan, in the journal Surgery Neurol. 1987: 27 pp. 543–547, by Elsevier Science Publishing Co., Inc. The Patent WO-A-88 09151 teaches a similar item of equipment.

In the abovementioned publications are described in particular a system and an operational mode on the basis of which a three-dimensional position marking system, of the probe type, makes it possible to mark the three-dimensional position coordinates of a nonhomogeneous structure, such as the head of a patient having to undergo a neurosurgical intervention, and then to put into correspondence as a function of the relative position of the nonhomoc.eneous structure a series of corresponding images consisting of two-dimensional images sectioned along an arbitrary direction, and obtained previously with the aid of a medical imaging method of the "scanner" type.

The system and the operational mode mentioned above offer a sure advantage for the intervening surgeon since the latter has available, during the intervention, apart from a direct view of the intervention, at least one two-dimensional sectional view enabling him to be aware, in the sectional plane, of the state of performance of the intervention.

However, and by virtue of the very design of the system and of the operational mode mentioned above, the latter allow neither a precise representation of the state of performance of the intervention, nor partially or totally automated conduct of the intervention in accordance with a program for advance of the instrument determined prior to the intervention.

Such a system and such an operational mode cannot therefore claim to eradicate all man-made risk, since the intervention is still conducted by the surgeon alone.

The objective of the present invention is to remedy the whole of the problem cited earlier, and in particular to propose a system permitting as exact as possible a correlation, at any instant, between an intervention modeling on the screen and the actual intervention, and furthermore the representation from one or more viewing angles, and if appropriate in one or more sectional planes, of the nonhomogeneous structure, the sectional plane or planes possibly being for example perpendicular to the direction of the path of advance of the instrument or of the intervention tool.

Another objective of the present invention is also the implementation of a system permitting simulation of an optimal trajectory of advance of the tool, so as to constitute an assisted or fully programed intervention.

Finally, an objective of the present invention is to propose a system making it possible, on the basis of the simulated trajectory and of the programed intervention, to steer the movement of the instrument or tool to the said trajectory so as to carry out the programed intervention.

The invention proposes to this effect an interactive system for local intervention inside a region of a nonhomogeneous structure to which is tied a reference structure containing a plurality of base points, characterized in that it comprises:

- means of dynamic display by three-dimensional imaging of a representation of the nonhomogeneous structure and of a reference structure tied to the nonhomogeneous structure, including images of the base points,
- means of delivering the coordinates of the images of the base points in the first reference frame,
- means of securing the position of the non-homogeneous structure and the reference structure with respect to a second reference frame.
- marker means for delivering the coordinates of the base points in the second reference frame,
- means of intervention comprising an active member whose position is determined with respect to the second reference frame,
- means of optimizing the transfer of reference frames from the first reference frame to the second reference frame and vice versa, on the basis of the coordinates of the images of the base points in the first reference frame and of the coordinates of the base points in the second reference frame, in such a way as to reduce to a minimum the deviations between the coordinates of the images of the base points in the first reference frame and the coordinates of the base points, expressed in the said first reference frame with the aid of the said reference frame transfer tools,
- means for defining with respect to the first reference frame a simulated origin of intervention and a simulated direction of intervention, and
- reference frame transfer means using the said reference frame transfer tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

A more detailed description of the system of the invention will be given below with reference to the drawings in which:

FIG. **1** represents a general view of an interactive system for local intervention inside a region of a nonhomogeneous structure according to the present invention,

FIG. **2** represents, in the case where the nonhomogeneous Structure consists of the head of a patient, and with a view to a neurosurgical intervention, a reference structure tied to the nonhomogeneous structure and enabling a correlation to be established between a "patient" reference frame and a reference frame of images of the patient which were made and stored previously,

FIG. **3** represents an advantageous embodiment of the spacial distribution of the reference structure of FIG. **2**,

FIG. **4** preesents an advantageous embodiment of the intervention means set up on an operating table in the case of a neurosirgical intervention,

FIGS. *5a* and *5b* represent a general flow diagram of functional steps implemented by the system,

FIGS. **6** thru **8** represent flow diagrams of programs permitting implementation of certain functional steps of FIG. **5***b*,

FIG. **9***a* represents a flow diagram of a program permitting implementation of a functional step of FIG. **5***a*,

FIG. **9***b* represents a flow diagram of a program permitting implementation of another functional step of FIG. **5***a*,

FIGS. **10***a* and **10***b* represent a general flow diagram of the successive steps of an interactive dialogue between the system of the present invention and the intervening surgeon and

FIG. **10***c* represents a general flow diagram of the successive functional steps carried out by the system of the invention, having (sic) the intervention, prior to the intervention, during the intervention and after the intervention.

The interactive system for local intervention according to the invention will firstly be described in connection with FIG. **1**.

A nonhomogeneous structure, denoted SNH, on which an intervention is to be performed, consists for example of the head of a patient in which a neurosurgical intervention is to be performed. It is however understood that the system of the invention can be used to carry out any type of intervention in any type of nonhomogeneous structure inside which structural and/or functional elements or units may be in evidence and whose integrity, during the intervention, is to be respected as far as possible.

The system comprises means, denoted **1**, of dynamic display by three-dimensional imaging, with respect to a first reference frame R_1, of a representation (denoted RSR) of a reference structure SR (described later) tied to the structure SNH, and a representation or modeling of the nonhomogeneous structure, denoted RSNH.

More precisely, the means **1** make it possible to display a plurality of successive three-dimensional images, from different angles, of the representations RSNH and RSR.

The system of the invention also comprises means, denoted **2**, of tied positioning, with respect to a second reference frame R_2, of the structures SNH and SR.

In the present non-limiting example, the head of the patient, bearing the reference structure SR, is fixed on an operating table TO to which are fixed the means **2** of tied positioning.

Of course, the patient whose head has been placed in the means **2** for tied positioning has previously been subjected to the customary preparations, in order to enable him to undergo the intervention.

The means **2** of the tied positioning with respect to R_2 will not be described in detail since they can consist of any means (such as a retaining headset) normally used in the field of surgery or neurosurgery. The reference frame R_2 can arbitrarily be defined as a tri-rectangular reference trihedron tied to the operating table TO, as represented in FIG. **1**.

Means **3** of marking, with respect to the second reference frame R_2, the coordinates, denoted X2, Y2, Z2, of arbitrary points, and in particular of a certain number of base points of the reference structure SR are furthermore provided.

These base points constituting the reference structure SR can consist of certain notable points and/or of marks fixed to the patient, at positions selected by the surgeon and in particular at these notable points.

The system of the invention further comprises computing means **4** receiving means **3** of marking the coordinates X2, X2, Z2.

The computing means **4**, as will be seen in detail later, are designed to elaborate optimal tools for reference frame transfer using on the one hand the coordinates in R_2, measured by the probe **3**, of a plurality of base points of the structure SR, and on the other hand the coordinates in R_1, determined by graphical tools of the computer **M01** (pointing by mouse, etc.), of the images of the corresponding base points in the representation RSR, so as to secure the best possible correlation between the information modeled in the computer equipment and the corresponding real-world information.

There is furthermore provision for reference frame transfer means **11** designed to use the tools thus elaborated and to secure this correlation in real time.

Moreover, means **40** are provided, as will be seen in detail later, for determining or modeling a reference origin of intervention ORI and a direction of intervention Δ.

With the aid of the means **11**, the modeled direction of intervention Δ can, at least prior to the intervention and at the start of the intervention, be materialized through an optical sighting system available to the surgeon, it being possible to steer this sighting system positionally with respect to the second reference frame R_2.

The sighting system will be described later.

The system of the present invention finally comprises means **5** of intervention comprising an active member, denoted **50**, whose position is specified with respect to the second reference frame R_2. The active member can consist of the various tools used in surgical intervention. For example, in the case of an intercranial neurosurgical intervention, the active member could be a trephining tool, a needle, a laser or radioscope emission head, or an endoscopic viewing system.

According to an advantageous characteristic of the invention, by virtue of the reference frame transfer means **11**, the position of the active member can be controlled dynamically on the basis of the prior modeling of the origin of intervention ORI and of the direction of intervention Δ.

The means **1** of dynamic display by three-dimensional imaging of the representations RSNH and RSR comprise a file **10** of two-dimensional image data. The file **10** consists for example of digitized data from tomographic sections, from radiographs, from maps of the patient's head, and contained in an appropriate mass memory.

The successive tomographic sections can be produced prior to the intervention in a conventional manner, after the reference structure SR has been put in place on the nonhomogeneous structure SNH.

According to an advantageous feature, the reference structure SR can consist of a plurality of marks or notable points which can be both sensed by the marker means **3** and detected on the two-dimensional images obtained.

Of course, the abovementioned two-dimensional tomographic sections can likewise be produced by any medical imaging means such as a nuclear magnetic resonance system.

In a characteristic and well-known manner, each two-dimensional image corresponding to a tomographic scanner section corresponds to a structural slice thickness of about 2 to 3 mm, the pixels or image elements in the plane of the tomographic section being obtained with a precision of the order of ±1 mm. It is therefore understood that the marks or points constituting the reference structure SR appear on the images with a positional uncertainty, and an important feature of the invention will consist in minimizing these uncertainties as will be described later.

The system also comprises first means **110** for calculating and reconstructing three-dimensional images from the data from the file **10**.

It also comprises a high-resolution screen **12** permitting the displaying of one or more three-dimensional or two-dimensional images constituting so many representations of the reference structure RSR and of the nonhomogeneous structure SNH.

Advantageously, the calculating means **110**, the high-resolution screen and the mass memory containing the file **10** form part of a computer of the workstation type with conventional design and denoted MO1.

Preferably, the first calculating means **110** can consist of a CAD type program installed in the workstation MO1.

By way of non-limiting example, this program can be derived from the software marketed under the tradename "AUTOCAD" by the "AUTODESK" company in the United States of America.

Such software makes it possible, from the various digitized two-dimensional images, to reconstruct threedimensional images constituting the representations of the structures RSR and RSNH in arbitrary orientations.

Thus, as has furthermore been represented in FIG. **1**, the calculating means **4** and **11** can consist of a third computer, denoted MO2 in FIG. 1.

The first and second computers MO1 and MO2 are interconnected by a conventional digital link (bus or network).

As a variant, the computers MO1 and MO2 can be replaced by a single workstation.

The marker means **3** consist of a three-dimensional probe equipped with a tactile tip **30**.

This type of three-dimensional probe, known per se and not described in detail, consists of a plurality of hinged arms, marked in terms of position with respect to a base integral with the operating table TO. It makes it possible to ascertain the coordinates of the tactile tip **30** with respect to the origin O_2 of the reference frame R_2 with a precision better than 1 mm.

The probe is for example equipped with resolvers delivering signals representing the instantaneous position of the abovementioned tactile tip **30**. The resolvers are themselves connected to the circuits for digital/analog conversion and sampling of the values representing these signals, these sampling circuits being interconnected in conventional manner to the second computer MO2 in order to supply it with the coordinates X2, X2, Z2 of the tactile tip **30**.

As a variant or additionally, and as represented diagrammatically, the marker means **3** can comprise a set of video cameras **31** and **32** (or else infrared cameras) enabling pictures to be taken of the structures SNH and SR.

The set of cameras can act as a stereoscopic system permitting the positional plotting of the base points of the reference structure SR, or of other points of the nonhomogeneous structure SNH, with respect to the second reference frame R_2. The positional plotting can be done for example by appending a laser beam emission system making it possible to illuminate successively the points whose coordinates are sought, appropriate software making it possible to then determine the position of these points one by one with respect to R_2. This software will not be described since it can consist of position and shape recognition software normally available on the market.

According to another variant, the marker means **3** can comprise a telemetry system.

In this case, the marks of the structure SR can consist of small radiotransmitters implanted for example on the relevant points of the patient's head and designed to be visible on the two-dimensional images, appropriate electromagnetic or optical sensors (not shown) being provided in order to determine the coordinates of the said marks in the reference frame R_2 or in a reference frame tied to the latter.

It is important to note here that the general function of the base points of the reference structure is, on the one hand, to be individually localizable on the reference structure, in order to deduce from this the coordinates in R_2, and on the other hand, to be visualizable on the two-dimensional images so as to be identified (by their coordinates in R_1) and included in the representation RSR on the screen.

It can therefore involve special marks affixed at arbitrary points of the lateral surface of the structure SNH, or else at notable points of the latter, or else, when the notable points can in themselves be localized with high precision both on the structure SNH and on the 2D sections, notable points totally devoid of marks.

In FIG. **2** a plurality of marks, denoted **M1** to Mi, these marks, in the case where the nonhomogeneous structure consists of the head of a patient, being localized for example between the eyebrows of the patient, on the latter's temples, and at the apex of the skull at a notable point such as the frontal median point.

More generally, for a substantially ovoid volume constituting the nonhomogeneous structure, there is advantageously provision for four base points at least on the outer surface of the volume.

Thus, as has been represented in FIG. **3**, the four marks **M1** to **M4** of the reference structure are distributed so as preferably to define a more or less symmetric tetrahedron. The symmetry of the tetrahedron, represented in FIG. **3**, is materialized by the vertical symmetry plane PV and the horizontal symmetry plane PH.

According to an advantageous characteristic, as will be seen later, the means of elaborating the reference frame transfer tools are designed to select three points of the tetrahedron which will define the "best plane" for the reference frame transfer.

Also, the presence of four or more points enables the additional point(s) to validate a specified selection.

More precisely, the presence of a minimum of four base points on the reference structure makes it possible to search for the minimum distortion between the points captured on the patient by the marker means consisting for example of the three-dimensional probe and the images of these points on the representation by three-dimensional imaging, the coordinates of which are calculated during processing. The best plane of the tetrahedron described earlier, that is to say the plane for which the uncertainty in the coordinates of the points between the points actually captured by the three-dimensional probe and the points of the representation of the reference structure RSR, is minimal, then becomes the reference plane for the reference frame transfer. Thus, the best correlation will be established between a modeled direction of intervention and a modeled origin of intervention, on the one hand, and the action of the member **50**. Preferably, the origin of intervention will be placed at the center of the region in which the intervention is to be carried out, that is to say a tumor observed or treated for example.

Furthermore, it will be possible to take the noted residual uncertainty into account in order to effect the representation of the model and of the tools on the dynamic display means.

A more detailed description of the means of intervention **5** will now be given in connection with FIG. **4**.

Preferably, the means of intervention **5** comprise a carriage **52** which is translationally mobile along the operating table TO, for example on a rack, denoted **54**, whilst being driven by a motor, not shown, itself controlled by the computer MO2 for example, via an appropriate link. This

movement system will not be described in detail since it corresponds to a conventional movement system available on the market. As a variant, the carriage **52** can be mobile over a distinct path separated from the operating table TO, or immobile with respect to the operating table and then constitute a support.

The support carriage **52** comprises in the first place a sighting member OV, constituting the above-mentioned sighting system, which can consist of a binocular telescope.

The sighting member OV enables the surgeon, prior to the actual intervention, or during the latter, to sight the presumed position of the region in which the intervention is to be carried out.

Furthermore, and in a non-limiting manner, with the sighting member OV can be associated a helium-neon laser emission system, denoted EL, making it possible to secure the aiming of a fine positioning or sighting laser beam on the structure SNH and in particular, as will be seen in detail later, to indicate to the surgeon the position of an entry point PE prior to the intervention, to enable the latter to open the skull at the appropriate location, and likewise to indicate to him what the direction of intervention will be. Additionally, the illuminating of the relevant point of the nonhomogeneous structure or at the very least the lateral surface of the latter enables the video cameras **31** and **32** to carry out, if necessary, a positional plotting.

Preferably, a system for measuring position by telemetry **53** is provided to secure the precise measurement of the position of the support carriage **52** of the sighting member OV and of the laser emission system EL. During the operation, and in order to secure the intervention, the carriage **52** can be moved along the rack **54**, the position of the carriage **52** being measured very precisely by means of the system **53**. The telemetry system **53** is interconnected with the microcomputer MO2 by an appropriate link.

The means of intervention **5** can advantageously consist of a guide arm **51** for the active member **50**.

The guide arm **51** can advantageously consist of several hinged segments, each hinge being equipped with motors and resolvers making it possible to secure control of movement of the end of the support arm and the positional plotting of this same end and therefore of the active member **50** according to six degrees of freedom with respect to the carriage **52**. The six degrees of freedom comprise, of course, three translational degrees of freedom with respect to a reference frame tied to the carriage **52** and three rotational degrees of freedom along these same axes.

Thus, the support arm **51** and the member **50** are marked in terms of instantaneous position with respect to the second reference frame R_2, on the one hand by way of the positional plot of the mobile carriage **52** and, on the other hand, by way of the resolvers associated with each hinge of the support arm **51**.

In the case of an intracranial neurosurgical surgical intervention, the active member **50** can be removed and can consist of a trephining tool, a needle or radioactive or chemical implant, a laser or radioisotope emission head or an endoscopic viewing system. These various members will not be described since they correspond to instruments normally used in neurosurgery.

The materializing of the modeled direction of intervention can be effective by means of the laser emitter EL. This sighting being performed, the guide arm **51** can then be brought manually or in steered manner into superposition with the direction of intervention Δ.

In the case of manual positioning, the resolvers associated with the sighting member OV and the laser emitter EL, if appropriate, make it possible to record the path of the sighting direction, constituting in particular the actual direction of intervention, on the representation of the nonhomogeneous structure in the dynamic display means **1**.

Furthermore, as will be described later and in preferential manner, the intervening surgeon will be able firstly to define a simulated intervention path and steer thereto the movements of the active member **50** in the nonhomogeneous structure in order effectively to secure all or part of the intervention.

In this case, the progress of the intervention tool **50** is then steered directly to the simulated path (data ORI, Δ) by involving the reference frame transfer means **11** in order to express the path in the reference frame R_2.

A more detailed description of the implementation of the operational mode of the system of the invention will now be described in connection with FIGS. *5a* and *5b*.

According to FIG. *5a*, the first step consists in obtaining and organizing in memory the two-dimensional image data (step **100**). Firstly, the nonhomogeneous structure SNH is prepared. In the case of a neurosurgical intervention for example, this means that the patient's head can be equipped with marks constituting the base points of the reference structure SR. These marks can be produced by means of points consisting of a dye partially absorbing the X-rays, such as a radiopaque dye.

The abovementioned marks are implanted by the surgeon on the patient's head at notable points of the latter [sic], and images can then be taken of the nonhomogeneous structure SNH by tomography for example, by means of an apparatus of the X-ray scanner type.

This operation will not be described in detail since it corresponds to conventional operations in the field of medical imaging.

The two-dimensional image data obtained are then constituted as digitized data in the file **10**, these data being themselves marked with respect to the reference frame R_1 and making it possible, on demand, to restore the two-dimensional images onto the dynamic display means **1**, these images representing superimposed sections of the nonhomogeneous structure SNH.

From the digitized image data available to the surgeon, the latter then proceeds, as indicated at **101** in FIG. *5a*, to select the structures of interest of the abovementioned images.

The purpose of this step is to facilitate the work of the surgeon by forming three-dimensional images which contain only the contours of the elements of the structure which are essential for geometrical definition and real-time monitoring of the progress of the intervention.

In the case where the nonhomogeneous structure SNH consists of the head of a patient, an analysis of the two-dimensional image data makes it possible, from values of optical density of the corresponding image-points, straightaway to extract the contours of the skull, to check the distance scales, etc.

Preferably, the abovementioned operations are performed on a rectangle of interest for a given two-dimensional image, this making it possible, by moving the rectangle of interest, to cover the whole of the image.

The above analysis is performed by means of suitable software which thus makes it possible to extract and vectorize the contours of the structures which will be modeled in the representations RSNH and RSR.

The structures modeled in the case of a neurosurgical intervention are for example the skull, the cerebral ventricles, the tumor to be observed or treated, the falx cerebri, and the various functional regions.

According to a feature of the interactive system of the invention, the surgeon may have available a digitizing table or other graphics peripheral making it possible, for each displayed two-dimensional image, to rectify or complete the definition of the contour of a particular region of interest.

It will be noted finally that by superimposing the extracted contours on the displayed two-dimensional image, the surgeon will be able to validate the extractions carried out.

The extracted contours are next processed by sampling points to obtain their coordinates in the reference frame R_1, it being possible to constitute these coordinates as an ASCII type file. This involves step **102** for generating the three-dimensional data base.

This step is followed by a step **103** of reconstructing the three-dimensional model. This step consists firstly, with the aid of the CAD type software, in carrying out on the basis of the contours of the structures of interest constituted as vectorized two-dimensional images an extrapolation between the various sectional planes.

The abovementioned extrapolation is carried out preferably by means of a "B-spline" type algorithm which seems best suited. This extrapolation transforms a discrete item of information, namely the successive sections obtained by means of the scanner analysis, into a continuous model permitting three-dimensional representation of the volume envelopes of the structures.

It should be noted that the reconstruction of the volumes constituting the structures of interest introduces an approximation related in particular to the spacing and non-zero thickness of the acquisition sections. An important characteristic of the invention, as explained in detail elsewhere, is on the one hand to minimize the resulting uncertainties in the patient-model correlation, and on the other hand to take into account the residual uncertainties.

The CAD type software used possesses standard functions which enable the model to be manipulated in space by displaying it from different viewpoints through just a criterion defined by the surgeon (step **104**).

The software can also reconstruct sectional representation planes of the nonhomogeneous structure which differ from the planes of the images from the file **10**, this making it possible in particular to develop knowledge enhancing the data for the representation by building up a neuroanatomical map.

The surgeon can next (step **105**) determine a model of intervention strategy taking into account the modeled structures of interest, by evaluating the distance and angle ratios on the two-and three-dimensional representations displayed.

This intervention strategy will consist, in actual fact, on the one hand in localizing the tumor and in associating therewith a "target point", which will subsequently be able to substitute for the origin common to all the objects (real and images) treated by the system, and on the other hand in determining a simulated intervention path respecting to the maximum the integrity of the structures of interest. This step can be carried out "in the office", involving only the workstation.

Once this operation is performed and prior to the intervention, the following phase consists in implementing the steps required to establish as exact as possible a correlation between the structure SNH (real world) and the representation RSNH (computer world). This involves steps **106** to **109** of FIG. *5b*.

Firstly, as represented in FIG. *5b* at step **107**, marking of the base points of the reference structure SR with respect to the second reference frame is carried out with the aid of the marker means **3**, by delivering to the system the coordinates X2, Y2, Z2 of the said base points.

The following step **106** consists in identifying on the representations RSNH and RSR displayed on the screen the images of the base points which have just been marked. More precisely, with the aid of appropriate graphics peripherals, these representations (images) of the base points are selected one by one, the workstation supplying on each occasion (in this instance to the computer MO2) the coordinates of these points represented in the reference frame R_1.

Thus the computer MO2 has available a first set of three-dimensional coordinates representing the position of the base points in R_2, and a second set of three-dimensional coordinates representing the position of the representations of the base points in R_1.

According to an essential feature of the invention, these data will be used to elaborate at **108**, **109**, tools for reference frame transfer (from R_1 to R_2 and vice versa) by calling upon an intermediate reference frame determined from the base points and constituting an intermediate reference frame specific to the reconstructed model.

More precisely, the intermediate reference frame is constructed from three base points selected so that, in this reference frame, the coordinates of the other base points after transfer from R_2 and the coordinates of the representations of these other base points after transfer from R_1 are expressed with the greatest consistency and minimum distortion.

When the step of elaborating the reference frame transfer tools is concluded, these tools can be used by he system to secure optimal coupling between the real world and the computer world (step **1110**).

Furthermore, according to a subsidiary feature of the present invention, the system can create on the display means a representation of the nonhomogeneous structure and of the intervention member which takes account of the deviations and distortions remaining after the "best" reference frame transfer tools have been selected (residual uncertainties). More precisely, from these deviations can be deduced by the calculating means a standard error likely to appear in the mutual positioning between the representation of the nonhomogeneous structure and the representation of elements (tools, sighting axes, etc.) referenced on R_2 when using the reference frame transfer tools. This residual uncertainty, which may in practice be given substance through an error matrix, can be used for example to represent certain contours (tool, structures of interest to be avoided during the intervention, etc.) with dimensions larger than those which would normally be represented starting from the three-dimensional data base or with the aid of coordinates marked in R_2, the said larger dimensions being deduced from the "normal" dimensions by involving the error matrix. For example, if the member were represented normally, in transverse section, by a circle of diameter D1, a circle of diameter D2>D1 can be represented in substance, with the difference D2-D1 deduced from the standard error value. In this way, when a direction of intervention will be selected making it possible to avoid traversing certain structures of interest, the taking into account of an "enlarged" size of the intervention tool will eradicate any risk of the member, because of the abovementioned errors, accidently traversing these structures.

Back at step **105**, and as will be seen in more detail with reference to FIGS. *9a* and *9b*, the reference origin of intervention ORI and the direction of intervention Δ, that is to say the simulated intervention path, can be determined according to various procedures.

According to a first procedure, the trajectory can be defined from two points, namely an entry point PE (FIG. **3**)

and a target point, that is to say substantially the center of the structure of interest consisting of the tumor to be observed or treated. Initially, these two points are localized on the model represented on the screen.

According to a second methodology, the trajectory can be determined from the abovementioned target point and from a direction which takes account of the types of structures of interest and of their positions with a view to optimally respecting their integrity.

After the abovementioned step **108**, the surgeon can at step **1110** perform the actual intervention.

The intervention can advantageously be performed by steering the tool or active member over the simulated intervention path, determined in step **1110**.

As a variant, given that the support arm **51** for the active member, equipped with its resolvers, continuously delivers the coordinates in R_2 of the said active member to the system, it is also possible to perform the operation manually or semi-manually, by monitoring on the screen the position and motions of a representation of the tool and by comparing them with the simulated, displayed intervention path.

It will furthermore be noted that the modeled direction of intervention can be materialized with the aid of the laser beam described earlier, the positioning of the latter (with respect to R_2) being likewise carried out by virtue of the reference frame transfer tools.

Certain functional features of the system of the invention will now be described in further detail with reference to FIGS. **6**, **7**, **8**, **9***a* and **9***b*.

The module for elaborating the reference frame transfer tools (steps **108**, **109** of FIG. **5***b*) will firstly be described with reference to FIG. **6**.

This module comprises a first sub-module **1001** for acquiring three points A, B, C, the images of the base points of SR on the representation RSNH (the coordinates of these points being expressed in the computer reference frame R_1), by successive selections of these points on the representation. To this effect, the surgeon is led, by means of a graphics interface such as a "mouse" to point successively at the three selected points A, B, C.

The module for preparing the transfer tools also comprises a second sub-module, denoted **1002**, for creating a unit three-dimensional orthogonal matrix M, this matrix being characteristic of a right-handed orthonormal basis represented by three unit vectors $\vec{i}$, $\vec{j}$, $\vec{k}$, which define an intermediate reference frame tied to R_1.

The unit vectors $\vec{i}$, $\vec{j}$ and $\vec{k}$ are given by the relations:

$$\vec{j} = \vec{AB} / \|AB\|$$

$$\vec{k} = \left(\vec{BA} \wedge \vec{BC} \right) / \| \vec{BA} \wedge \vec{BC} \|$$

$$\vec{i} = \vec{j} \wedge \vec{k}$$

where $\|\ \|$ designates the norm of the relevant vector.

In the above relations, the sign "$\wedge$" designates the vector product of the relevant vectors.

Similarly, the module for preparing the transfer tools comprises a third sub-module, denoted **1003**, for acquiring three base points D, E, F, of the structure SR, these three points being those whose images on the model are the points A, B, C respectively. For this purpose, the surgeon, for example by means of the tactile tip **30**, successively senses these three points to obtain their coordinates in R_2.

The sub-module **1003** is itself followed, as represented in FIG. **6**, by a fourth sub-module **1004** for creating a unit three-dimensional orthogonal matrix N, characteristic of a right-handed orthonormal basis comprising three unit vectors $\vec{i}'$, $\vec{j}'$ $\vec{k}'$ and which is tied to the second reference frame R_2 owing to the fact that the nonhomogeneous structure SNH is positionally tied with respect to this reference frame.

The three unit vectors $\vec{i}'$, $\vec{j}'$, $\vec{k}'$ are defined by the relations:

$$\vec{j}' = \vec{DE} / \| \vec{DE} \|$$

$$\vec{k}' = \left(\vec{ED} \wedge \vec{EF} \right) / \| \vec{ED} \wedge \vec{EF} \|$$

$$\vec{i}' = \vec{j}' \wedge \vec{k}'$$

As indicated above, to the extent that the base points of the reference structure can be marked in R_2 with high precision, so their representation in the computer base R_1 is marked with a certain margin of error given on the one hand the non-zero thickness (typically from 2 to 3 mm) of the slices represented by the two-dimensional images from the file **10**, and on the other hand (in general to a lesser extent) the definition of each image element or pixel of a section.

According to the invention, once a pair of transfer matrices M, N has been elaborated with selected points A, B, C, D, E, F, it is sought to validate this selection by using one or more additional base points; more precisely, for the or each additional base point, this point is marked in R_2 with the aid of the probe **30**, the representation of this point is marked in R_1 after selection on the screen, and then the matrices N and M are applied respectively to the coordinates obtained, in order to obtain their expressions in the bases ($\vec{i}'$, $\vec{j}'$, $\vec{k}'$) and ($\vec{i}$, $\vec{j}$, $\vec{k}$) respectively. If these expressions are in good agreement, these two bases can be regarded as a single intermediate reference frame, this securing the exact as possible mathematical coupling between the computer reference frame R_1 tied to the model and the "real" reference frame R_2 tied to the patient.

In practice, the module for elaborating the reference frame transfer tools can be designed to perform steps **1001** to **1004** in succession on basic triples which differ on each occasion (for example, if four base points have been defined associated with four representations in RSR, there are four possible triples), in order to perform the validation step **1005** for each of these selections and finally in order to choose the triple for which the best validation is obtained, that is to say for which the deviation between the abovementioned expressions is smallest. This triple defines the "best plane" mentioned elsewhere in the description, and results in the "best" transfer matrices M and N.

As a variant, it will be possible for the selection of the best plane to be made at least in part by the surgeon by virtue of his experience.

It should be noted that the reference frame transfer will only be concluded by supplementing the matrix calculation with the matrices M, N with a transfer of origin, so as to create a new common origin for example at the center of the tumor to be observed or treated (point ORI). This transfer of origin is effected simply by appropriate subtraction of vectors on the one hand on the coordinates in R_1, and on the other hand on the coordinates in R_2. These vectors to be subtracted are determined after localization of the center of the tumor on the representation.

Furthermore, the means described above for establishing the coupling between the patient's world and the model's world can also be used to couple to the model's world that of map data, also stored in the workstation and expressed in a different reference frame denoted R_3. In this case, since these data contain no specific visible mark, the earlier described elaboration of matrices is performed by substituting for these marks the positions of notable points of the patient's head. These may be temporal points, the frontal median point, the apex of the skull, the center of gravity of the orbits of the eyes, etc.

The corresponding points of the model can be obtained either by selection by mouse or graphics tablet on the model, or by sensing on the patient himself and then using the transfer matrices.

The above step of elaborating the reference frame transfer tools, conducted in practice by the calculating means **4**, makes it possible subsequently to implement the reference frame transfer means (FIGS. **7** and **8**).

With reference to FIG. **7**, the first transfer sub-module **201** comprises a procedure denoted **2010** for aquiring the coordinates XM, YM, ZM, expressed in R_1, of the point to be transferred, by selecting on the representation.

The procedure **2010** followed by a procedure **2011** for calculating the coordinates XP, YP, ZP (expressed in R_2) of the corresponding real point on the patient through the transformation:

{XP, YP, ZP}=M*N^{-1}*{XM, YM, ZM} where M * N^{-1} represents the product of the matrix M and the inverse matrix N.

The procedure **2011** is followed by a processing procedure **2012** utilizing the calculated coordinates XP, YP, ZP, for example to indicate the corresponding point on the surface of the structure SNH by means of the laser emission system EL, or again to secure the intervention at the relevant point with coordinates XP, YP, ZP (by steering the active member).

Conversely, in order to secure a transfer from SNH to RSNH, the second sub-module **202** comprises (FIG. **8**) a procedure denoted **2020** for acquiring on the structure SNH the coordinates XP, YP, ZP (expressed in R_2) of a point to be transferred.

These coordinates can be obtained by means of the tactile tip **30** for example. The procedure **2020** is followed by a procedure **2021** for calculating the corresponding coordinates XM, YM, ZM in R_1 through the transformation:

{XM, YM, ZM}=N*M^{-1}*{XP, YP, ZP}

A procedure **2022** next makes it possible to effect the displaying of the point with coordinates XM, YM, ZM on the model or again of a straight line or of a plane passing through this point and furthermore meeting other criteria.

It will be noted here that the two sub-modules **201, 202** can used [sic] by the surgeon at any moment for the purpose of checking the valid nature of the transfer tools; in particular, it is possible to check at any time that a real base point, with coordinates known both in R_2 and R_1 (for example a base point of SR or an arbitrary notable point of the structure SNH visible on the images), correctly relocates with respect to its image after transferring the coordinates in step **2011**.

In the event of an excessive difference, a new step of elaboration of the transfer tools is performed.

Furthermore, the sub-modules **201, 202** can be designed to also integrate the taking into account of the residual uncertainty, as spoken of above, so as for example to represent on the screen a point sensed not in a pointwise manner, but in the form for example of a circle or a sphere representing the said uncertainty.

From a simulated intervention path, for example on the representation RSNH, or from any other straight line selected by the surgeon, the invention furthermore enables the model to be represented on the screen from a viewpoint corresponding to this straight line. Thus the third transfer subroutine comprises, as represented in FIGS. **9***a* and **9***b*, a first module **301** for visualizing the representation in a direction given by two points and a second module **302** for visualizing the representation in a direction given by an angle of elevation and an angle of azimuth.

The first module **301** for visualizing the representation in a direction given by two points comprises a first sub-module denoted **3010** permitting acquisition of the two relevant points which will define the selected direction. The coordinates of these points are expressed in the reference frame R_1, these points having either been acquired previously on the nonhomogeneous structure SNH for example by means of the tactile tip **30** and then subjected to the reference frame transfer, or chosen directly on the representation by means of the graphics interface of the "mouse" type.

The first sub-module **3010** is followed by a second sub-module denoted **3011** permitting the creation of a unit, orthogonal three-dimensional matrix V characteristic of a right-handed orthonormal basis $\vec{i}''$, $\vec{j}''$, $\vec{k}''$ the unit vectors $\vec{i}''$, $\vec{j}''$, $\vec{k}''$, being determined through the relations:

$$\vec{k}'' = \vec{AB}/\|\vec{AB}\|;$$
$$\vec{i}'' \cdot \vec{k}'' = O; \vec{i}'' \cdot \vec{z}'' = O; \|\vec{i}''\| = 1;$$
$$\vec{j}'' = \vec{k}'' \wedge \vec{j}''$$

where "Λ" represents the vector product and "." symbolizes the scalar product.

The sub-module **3011** is followed by a routine **3012** making it possible to secure for all the points of the entities (structures of interest) of the three-dimensional data base of coordinates XW, YW, ZW in R_1 a conversion into the orthonormal basis ($\vec{i}''$, $\vec{j}''$, $\vec{k}''$) by the relation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The subroutine **3013** is then followed by a subroutine **3014** for displaying the plane i", j", the subroutines **3013** and **3014** being called up for all the points, as symbolized by the arrow returning to block **3012** in FIG. **9***a*.

When all the points have been processed, an output module **3015** permits return to a general module, which will be described later in the description. It is understood that this module enables two-dimensional images to be reconstructed in planes perpendicular to the direction defined by A and B.

In the same way, the second module **302** (FIG. **9***b*) for visualizing the representation from a viewpoint given by an angle of elevation and an angle of azimuth comprises a first sub-module **3020** for acquiring the two angles in the representation frame of reference.

The selection of the angles of elevation and of azimuth can be made by selecting from a predefined data base or by moving software cursers associated with each view or else by modification relative to a current direction, such as the modeled direction of intervention. The sub-module **3020** is itself followed by a second sub-module **3021** for creating a unit orthoganal three-dimensional matrix W characteristic of a right-handed orthonormal basis of unit vectors $\vec{i}'''$, $\vec{j}'''$, $\vec{k}'''$. They are defined by the relations:

$$\vec{i}''' \cdot \vec{k}''' = O;$$

$$\vec{k}''' \cdot \vec{z}''' = \sin(\text{azimuth})$$

$$\vec{j}''' \cdot \vec{z}''' = O;$$

$$\vec{i}''' \cdot \vec{y} = \cos(\text{elevation});$$

$$\vec{i}'''' \cdot \vec{x}''' = \sin(\text{elevation})$$

$$\vec{j}''' = \vec{k}''' \wedge \vec{i}'''$$

A routine **3022** is then called for all the points of the entities of the three-dimensional data base of coordinates XW, YW, ZW and enables a first sub-routine **3023** to be called permitting calculation of the coordinates of the relevant point in the right-handed orthonormal bases $\vec{i}'''$, $\vec{j}'''$ $\vec{k}'''$ through the transformation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The sub-routine **3023** is itself followed by a sub-routine **3024** for displaying the plane i''', j''', the two sub-routines **3023** and **3024** then being called up for each point as symbolized by the return via the arrow to the block **3022** for calling the abovementioned routine. When all the points have been processed, an output sub-module **3025** permits a return to the general menu.

Of course, all of the programs, sub-routines, modules, sub-modules and routines destroyed earlier are managed by a general "menu" type program so as to permit interactive driving of the system by screen dialogue with the intervening surgeon by specific screen pages.

A more specific description of a general flow diagram illustrating this general program will now be given in connection with FIGS. **10***a* and **10***b*.

Thus, in FIG. **10***a* has been represented in succession a screen page **4000** relating to the loading of data from the digitized file **10**, followed by a screen page **4001** making it possible to secure the parameterizing of the grey scales of the display on the dynamic display means **1** and to calibrate the image, for example.

The screen page **4001** is followed by a screen page **4002** making it possible to effect the generation of a global view and then a step or screen page **4003** makes it possible to effect an automatic distribution of the sections on the screen of the workstation.

A screen page **4004** makes it possible to effect a manual selection of sections and then a screen page **4005** makes it possible to effect the selection of the strategy (search for the entry points and for the possible directions of intervention, first localizing of the target (tumor . . .) to be treated . . .), as defined earlier, and to select the position and horizontal, sagittal and frontal distribution of the sections.

A screen page **4006** also makes it possible to effect a display of the settings of a possible stereotaxic frame.

It will be recalled that the reference structure SR advantageously replaces the stereotaxic frame formerly used to effect the marking of position inside the patient's skull.

There may furthermore be provided a screen-page **4007** for choosing strategic sections by three-dimensional viewing, on selection by the surgeon, and then at **4008** the aligning of the references of the peripherals (tool, sighting members, etc., with the aid of the probe **30**.

A screen page **4009** is also provided to effect the search for the base points on the patient with the aid of the said probe, following which the steps of construction of the reference frame transfer tools and of actual reference frame transfer are performed, preferably in a user-transparent manner.

Another screen page **4010** is then provided, so as to effect the localizing of the target on the representation (for example a tumor to be observed or treated in the case of a neurosurgical intervention) in order subsequently to determine a simulated intervention path.

Then a new screen page **4011** makes it possible to effect the setting of the guides for the tool on the basis of this simulated path before opening up the skin and bone flaps on the patient's skull.

Then a new localizing step **4012** makes it possible to check whether the position of the guides corresponds correctly to the simulated intervention path.

The screen page **4012** is followed by a so-called intervention screen page, the intervention being performed in accordance with step **1110** of FIG. **5***b*.

A more detailed description of the interactive dialogue between the surgeon and the system during a surgical, and in particular a neurosurgical, intervention will follow with reference to FIG. **10***c* and to all of the preceding description.

The steps of FIG. **10***c* are also integrated in the general program mentioned earlier; there are undertaken in succession a first phase I (preparation of the intervention), then a second phase II, (prior to the actual intervention, the patient is placed in a condition for intervention, the reference structure SR being tied to the second reference frame R_2), then a third phase III (intervention) and finally a post-intervention phase IV.

With a view to preparing the intervention, the system requests the surgeon (step **5000**) to choose the elementary structures of interest (for example bones of the skull, ventricles, vascular regions, the tumor to be explored or treated, and the images of the marks constituting in the first reference frame the representation RSR).

The choice of the elementary structures of interest is made on the display of the tomographic images, for example, called up from the digitized file **10**.

The system next performs, at step **5001**, a modeling of the structures of interest, as described earlier. Then, the nonhomogeneous structure having been thus constituted as a three-dimensional model RSNH displayed on the screen, the intervening surgeon is then led to perform a simulation by three-dimensional imaging, at step **5002**, with a view to defining the intervention path of the tool **50**.

During phase II the patient being placed in a condition for intervention and his head and the reference structure SR being tied to the second reference frame R_2, the surgeon performs at step **5003** a search for the position of the marks M1 to M4 constituting base points of the reference structure in the second reference frame R_2, and then during a step **5004**, performs a search for the position of the sighting systems, visualizing member OV, or of the tools and intervention instruments **50**, still in the second reference frame R_2, so as, if appropriate, to align these implements with respect to R_2.

The system then performs the validation of the intervention/patient spaces and representation by three-dimensional imaging in order to determine next the common origin of intervention ORI. In other words, the matrix reference frame transfer described above is supplemented with the necessary origin translations (origins **01** and **02** aligned on ORI).

This operation is performed as described earlier.

Phase III corresponds to the intervention, during which the system effects at step **5006** a permanent coupling in real time between the direction of aim of the active member **50**, and/or of the direction of aim of the sighting member OV (and if appropriate of the laser beam), with the direction of aim (of observation) simulated by three-dimensional imaging on the display means **1**, and vice versa.

In the following step **5007**, the coupling is effected of the movements and motions of the intervention instrument with their movements simulated by three-dimensional imaging, with automatic or manual conduct of the intervention.

As noted at **5008**, the surgeon can be supplied with a permanent display of the original two-dimensional sectional images in planes specified with respect to the origin ORI and to the direction of intervention. Such a display enables the surgeon at any time to follow the progress of the intervention in real time and to be assured that the intervention is proceeding in accordance with the simulated intervention. In phase IV which is executed after the intervention, the system effects a saving of the data acquired during the intervention, this saving making it possible subsequently to effect a comparison in real time or deferred in the event of successive interventions on the same patient.

Furthermore, the saved data make it possible to effect a playback of the operations carried out with the option of detailing and supplementing the regions traversed by the active member **50**.

Thus, a particularly powerful interactive system for local intervention has been described.

Thus, the system which is the subject of the present invention makes it possible to represent a model containing only the essential structures of the nonhomogeneous structure, this facilitating the work of preparation and of monitoring of the intervention by the surgeon.

Moreover, the system, by virtue of the algorithms used and in particular by minimizing the distortion between the real base points and their images in the 2D sections or the maps, makes it possible to establish a two-way coupling between the real world and the computer world through which the transfer errors are minimized, making possible concrete exploitation of the imaging data in order to steer the intervention tool.

To summarize, the system makes possible an ineractive [sic] medical usage not only to create a three-dimensional model of the nonhomogeneous structure but also to permit a marking in real time with respect to the internal structures and to guide the surgeon in the intervention phase.

More generally, the invention makes it possible to end up with a coherent system in respect of:

- the two-dimensional imaging data (scanner sections, maps, etc.)
- the three-dimensional data base;
- the data supplied by the marker means **3** in the reference frame R_2;
- the coordinate data for the sighting systems and intervention tools;
- the real world of the patient on the operating table.

Accordingly, the options offered by the system are, in a non-limiting manner, the following:

- the tools and of [sic] their position can be represented on the screen;
- the position of a point on the screen can be materialized on the patient for example with the aid of the laser emission device EL;
- the orientation and the path of a tool such as a needle can be represented on the screen and materialized on the patient optically (laser emission) or mechanically (positioning of the guide-arm in which the tool is guided in translation):
- an image of the patient, yielded for example by a system for taking pictures if appropriate in relief, can be superimposed on the three-dimensional representation modeled on the screen; thus, any change in the soft external parts of the patient can be visualized as compared with the capture by the scanner;
- it being possible for the surgeon's field of view given by a sighting member (such as a surgical microscope) to be referenced with respect to R_2, the direction of visualization of the model on the screen can be made identical to the real sight by the sighting member;
- finally, the three-dimensional images, normally displayed on the screen in the preceding description, may as a variant be introduced into the surgeon's microscope so as to obtain the superposition of the real image and the representation of the model.

We claim:

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

- means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;
- means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;
- means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;
- means for determining a set of coordinates of the plurality of base points in the second reference frame;
- means of intervention comprising an active member whose position is determined with respect to the second reference frame;
- means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;
- means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,
- means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim **1**, wherein the plurality of reference frame translation tools comprise:

- means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;
- means for creating a matrix (N) for transferring between the second reference frame and a second intermediate

reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

$\{YP,YP, ZP\}=M*N^{-1} *\{XM,YM,ZM\}$ where $M * N^{-1}$ represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

$\{YM, YM, ZM\}=N*M^{-1} *\{XP,ZP,ZP\}$ where $N*M^{-1}$ represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.: 5,868,675

DATED: February 9, 1999

INVENTOR(S): Henrion et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Title, item [54], delete "NONHUMOGENEOUS STRUCTURE" and insert — NON-HOMOGENEOUS STRUCTURE --.

At item [22], the PCT filing date, delete "May 10, 1990" and insert — October 5, 1990 --.

Signed and Sealed this

Eighth Day of May, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

Listing Of Claims

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;

means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;

means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;

means for determining a set of coordinates of the plurality of base points in the second reference frame;

means of intervention comprising an active member whose position is determined with respect to the second reference frame;

means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference

frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;

means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,

means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim 1, wherein the plurality of reference frame translation tools comprise:

means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;

means for creating a matrix (N) for transferring between the second reference frame and a second intermediate reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

{YP,YP, ZP}=M*N.sup.-1 *{XM,YM,ZM} where M * N.sup.-1 represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

{YM, YM, ZM}=N*M.sup.-1 *{XP,ZP,ZP} where N*M.sup.-1 represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

17. (Canceled)

18. (Canceled)

19. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention; and

a tracking system operable to determine a position of at least the second reference structure and a position of the active member and configured to transmit the determined positions of the second reference structure and the active member to the controller;

wherein the controller is configured to determine the position of the active member based on the determined position of at least the active member and the correlation of the first reference structure and the second reference structure.

20. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure includes a plurality of base points.

21. (previously presented) The interactive system as defined in Claim 20 wherein the second reference structure includes a plurality of tracking markers.

22. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure includes a plurality of tracking markers.

23. (previously presented) The interactive system as defined in Claim 22 wherein the plurality of tracking markers are attached to the patient.

24. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is attached to the patient.

25. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is attached to the patient.

26. (previously presented) The interactive system as defined in Claim 21 wherein the plurality of base points are generated from the plurality of tracking markers.

27. (previously presented) The interactive system as defined in Claim 20 wherein the plurality of base points are at least one of a plurality of notable points on the patient and marks fixed to the patient.

28. (previously presented) The interactive system as defined in Claim 27 wherein the notable points are selected from a group comprising a head, eyebrows, temples, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

29. (previously presented) The interactive system as defined in Claim 19 wherein the tracking system includes a marker device operable to determine a position of the second reference structure in relation to the patient reference frame.

30. (Amended) The interactive system as defined in Claim 29 wherein the marker device includes a telemetry system operable to determine the position of the second reference structure in the patient reference frame and transmit the determined position to the controller, wherein the controller is operable to perform the correlation at least with the transmitted determined position.

31. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an electromagnetic telemetry system.

32. (previously presented) The interactive system as defined in Claim 31 wherein the second reference structure includes electromagnetic tracking markers, wherein the electromagnetic telemetry system is operable to determine the position of the electromagnetic tracking markers of the second reference structure in relation to the patient reference frame.

33. (previously presented) The interactive system as defined in Claim 32, wherein the electromagnetic tracking markers are transmitters and the electromagnetic telemetry system is an electromagnetic sensor.

34. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an optical telemetry system.

35. (Amended) The interactive system as defined in Claim 34 wherein the optical telemetry system includes at least one of a video camera or an infrared camera to image at least the second reference structure and configured to plot points of the second reference structure.

36. (previously presented) The interactive system as defined in Claim 34 wherein the second reference structure includes optical tracking markers, wherein the optical telemetry system is operable to determine the position of the optical tracking markers of the second reference structure in relation to the patient reference frame.

37. (previously presented) The interactive system as defined in Claim 34 wherein the optical telemetry system utilizes position and shape recognition to identify the second reference structure.

38. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a three-dimensional probe.

39. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe includes a tactile tip operable to engage the second reference structure.

40. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe is robotically manipulated, such that the instantaneous position of the three-dimensional probe is known.

41. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a set of cameras operable to determine the position of the second reference structure in relation to the patient reference frame.

42. (previously presented) The interactive system as defined in Claim 41 wherein the set of cameras are selected from video and infrared cameras.

43. (previously presented) The interactive system as defined in Claim 29 wherein the marker device is a laser beam emission system operable to illuminate the second reference structure to determine a position of the second reference structure in relation to the patient reference frame.

44. (previously presented) The interactive system as defined in Claim 20 wherein the controller further includes a graphical tool operable to identify the plurality of

base points of the first reference structure in the image data of the image data reference frame.

45. (previously presented) The interactive system as defined in Claim 44 wherein the graphical tool is a mouse in communication with the controller.

46. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is generated from the second reference structure.

47. (canceled)

48. (Amended) The interactive system as defined in Claim 19 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

49. (Amended) The interactive system as defined in Claim 19 further comprising a telemetry system operable to determine the position of the active member in the patient reference frame, said telemetry system in communication with the controller.

50. (previously presented) The interactive system as defined in Claim 49 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

51. (Amended) The interactive system as defined in Claim [[47]] 19 wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame.

52. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

53. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to model a reference origin of intervention and a direction of intervention and said display is further operable to display the modeled reference origin of intervention and direction of intervention.

54. (Amended) The interactive system as defined in Claim 51 wherein the display is further operable to display the real-time position of the active member in the image reference frame based on the determined position of the active member with the tracking system.

55. (previously presented) The interactive system as defined in Claim 51 wherein the display is further operable to display image data relative to a direction of intervention of the active member.

56. (previously presented) The interactive system as defined in Claim 55 wherein the image data is displayed perpendicular to a direction of intervention of the active member.

57. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to simulate an optimal trajectory of advance of the active member and said display is operable to display the optimal trajectory in the image data relative to the image reference frame.

58. (previously presented) The interactive system as defined in Claim 57 wherein movement of the active member is steered to the optimal trajectory to carry out a programmed intervention.

59. (Amended) The interactive system as defined in Claim 19 wherein the active member is robotically controlled.

60. (previously presented) The interactive system as defined in Claim 19 wherein the image data is at least one of a magnetic resonance image data, a

tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

61. (previously presented) The interactive system as defined in Claim 19 wherein the device is operable to construct three-dimensional images from captured two-dimensional images.

62. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient; and

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

wherein the device is operable to construct three-dimensional images from captured two-dimensional images;

wherein the controller is operable to superimpose two-dimensional image data on the three-dimensional images wherein any change in soft external parts of the patient can be visualized as compared with the image captured by the imaging device.

63. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame; and

an active member operable to perform the intervention;

wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame;

wherein the controller is further operable to determine residual uncertainty which is used to represent a contour with dimensions larger than those which would normally be represented and the display is operable to display the residual uncertainty of the contour.

64. (previously presented) The interactive system as defined in Claim 63 wherein the contour is a display of an active member and a representation of residual uncertainty in order to reduce the chance of traversing undesired structures.

65. (previously presented) The interactive system as defined in Claim 19 wherein the controller is further operable to correlate map data in a map reference frame with the patient reference frame.

66. (Amended) The interactive system as defined in Claim 19 wherein the intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

67. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is fixed to a head set.

68. (previously presented) The interactive system as defined in Claim 60 wherein the head set is further fixed to an operating table.

69. (previously presented) The interactive system as defined in Claim 19 wherein the device further includes memory operable to store the image data.

70. (previously presented) The interactive system as defined in Claim 19 wherein the device is a first computer.

71. (previously presented) The interactive system as defined in Claim 70 wherein the controller is a second computer.

72. (previously presented) The interactive system as defined in Claim 71 wherein the first computer and the second computer is a single work station.

73. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention inside the region of the patient;

a tracking system operable to track the position of the active member in relation to the patient reference frame, the tracking system being in communication with the controller to transmit the tracked position of the active member as position information to the controller, wherein the controller is operable to determine the position of the active member relative to the image reference frame; and

a display operable to display the real-time position of the active member in the image reference frame based on the controller determined position of the active member based on the tracked position of the active member from the tracking system, wherein the controller is configured to generate a representation of the active member that is displayed on the display relative to a display of the received image data.

74. (previously presented) The interactive system as defined in Claim 73 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

75. (previously presented) The interactive system as defined in Claim 73 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

76. (previously presented) The interactive system as defined in Claim 73 wherein the tracking system that tracks the position of the active member is a telemetry system in communication with the controller.

77. (previously presented) The interactive system as defined in Claim 73 wherein the active member is robotically controlled.

78. (previously presented) The interactive system as defined in Claim 73 wherein the image data is at least one of a magnetic resonance image data, a tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

79. (previously presented) The interactive system as defined in Claim 73 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

80. (previously presented) The interactive system as defined in Claim 73 wherein the first reference structure includes a plurality of base points.

81. (previously presented) The interactive system as defined in Claim 80 wherein the second reference structure includes a plurality of tracking markers.

82. (previously presented) The interactive system as defined in Claim 81 wherein the plurality of base points are generated by the plurality of tracking markers.

83. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is attached to the patient.

84. (previously presented) The interactive system as defined in Claim 73 wherein intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery intervention, and combinations thereof.

85. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is fixed to a head set.

86. (Amended) The interactive system as defined in Claim 73 wherein the display forms part of the device and wherein the image data received is acquired image data of the region of the patient and is displayed on the display, further wherein the representation of the active member is displayed on the acquired image data of the region of the patient.

87. (Twice Amended) A method for performing an image guided intervention inside a region of a patient, said method comprising:

accessing a first image data of the region of the patient captured with an imaging system where the first image data includes image data of a first reference structure;

identifying the first reference structure in the first image data to establish an image reference frame;

identifying a second reference structure relative to the patient to establish a patient reference frame;

correlating the position of the first reference structure in the image reference frame in the first image data with the position of the second reference structure in the patient reference frame; and

tracking an active member at least to determine a position of the active member in the patient reference frame to determine a location of the active member based on the tracking of the active member and transmitting the determined position in the patient refrence frame for display on a display device relative to the image reference frame of the first image data based at least on the correlation of the first reference structure and the second reference structure.

88. (previously presented) The method as defined in Claim 87 further comprising attaching a plurality of tracking markers to the patient where the tracking markers form the second reference structure.

89. (previously presented) The method as defined in Claim 88 further comprising identifying the position of the tracking markers in the patient reference frame using a telemetry system.

90. (Amended) The method as defined in Claim 89 further comprising transmitting from the tracking markers a signal and receiving the transmitted signal with an electromagnetic sensor to identify the position of the second reference structure in the patient reference frame.

91. (previously presented) The method as defined in Claim 87 wherein identifying the first reference structure includes identifying a plurality of base points visible in the image data.

92. (previously presented) The method as defined in Claim 91 wherein identifying the plurality of base points includes identifying at least one of notable points on the patient as marks fixed to the patient representing the plurality of base points.

93. (previously presented) The method as defined in Claim 92 wherein the notable points are selected from a group comprising a head, eyebrows, temporal point, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

94. (previously presented) The method as defined in Claim 91 wherein the plurality of base points visible in the image data are generated from the plurality of tracking markers attached to the patient.

95. (previously presented) The method as defined in Claim 87 further comprising attaching the second reference structure to the patient.

96. (previously presented) The method as defined in Claim 87 further comprising displaying the image data of the region of the patient, including displaying the first reference structure.

97. (previously presented) The method as defined in Claim 87 further comprising performing an intervention on the patient with an active member.

98. (Canceled)

99. (Amended) The method as defined in Claim 96 further comprising:

displaying the position of the active member as a representation of the active member in the accessed first image data that is captured image data that is correlated to the patient based on the correlation and displayed on a display device with the position of the active member being correlated between the patient reference frame defined by the first reference structure fixed to the patient and the image reference frame based on the tracking of the active member.

100. (Amended) The method as defined in Claim 99 further comprising identifying the position of the active member with a telemetry system by transmitting the tracked location of the active member for displaying the representation of the active member.

101. (previously presented) The method as defined in Claim 99 further comprising displaying a reference origin of intervention and a direction of intervention in the image data.

102. (previously presented) The method as defined in Claim 101 further comprising tracking the position of the active member relative to the reference origin of intervention and the direction of intervention.

103. (previously presented) The method as defined in Claim 87 further comprising converting two-dimensional image data to three-dimensional image data.

104. (previously presented) The method as defined in Claim 97 wherein the intervention is selected from at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

105. (previously presented) The method as defined in Claim 95 further comprising attaching the second reference structure to a head set.

ATTACHMENT C

Taylor, Michael

From: Kimberly Wallace <kwallace@globlanglinks.com>
Sent: Tuesday, August 30, 2011 12:37 PM
To: Taylor, Michael
Subject: RE: Translation Quote Request (5074A-000013/REA)

Hi Michael,

Not a problem. We can get it done for you [redacted] and deliver by tomorrow.

Thank you for your business!!

Best Regards,

Kimberly Wallace
Global Language Links LLC
Office: 248-283-0615
Fax: 877-800-9526
kwallace@globlanglinks.com
www.GlobLangLinks.com

From: Taylor, Michael [mailto:mltaylor@HDP.com]
Sent: Tuesday, August 30, 2011 11:48 AM
To: Kimberly Wallace
Subject: RE: Translation Quote Request (5074A-000013/REA)

[redacted]

Thank you,

Michael

--Begin text for translation:

Dear ______,

As you may recall, you communicated with Rick Warner or Christopher Eusebi in late 2002 and early 2003 regarding a reissue application of U.S. Patent 5,568,675 (attached hereto). At that time you executed a Re-issue declaration.

During our work with the U.S. Patent office to obtain a grantable patent we amended the claims to those in the attached "Current Claims," which we provide for your review. Per the rules of a reissue application, we will file a Supplemental Re-issue declaration. We have attached a "Supplemental Reissue Declaration" for your execution. We believe that this should be the last paper for this application. Once the U.S. Patent office receives this executed paper a re-issue patent should be granted. A re-issue patent essentially replaces the original patent.

Please execute and return to us the executed "Supplemental Reissue declaration." A return email or fax is acceptable. If you can not email or fax an executed copy to us and require returning a physical copy, we can provide a DHL account number to cover the expense of shipping a paper copy to us.

In the table below is the current contact information we have for each of inventor. Please confirm that the current contact information is correct. Also, if you can provide us with an email address for Jean-Baptiste Thiebaut we would appreciate it very much.

We thank you very much in advance for your assistance and quick response.

:End Text for translation--

HARNESS DICKEY Michael L. Taylor | Patent Attorney
O | 248.641.1600 D | 248.641.1289 F | 248.641.0270
IP Causes Worldwide

From: Kimberly Wallace [mailto:kwallace@globlanglinks.com]
Sent: Monday, August 29, 2011 10:29 AM
To: Taylor, Michael
Subject: RE: Translation Quote Request (5074A-000013/REA)

Hi Michael,

When you say rush does that mean you need then in an hour or two hours or just same day by end of business? Turnaround time depends on the availability of my translators. Does that make sense? Typically, we can get it done by end of day if not sooner.

Our min cost is $60 typically for a half page and $120 for a full page and if you need it the same day or "rush" there is an additional 20% added on.

We also offer telephonic translation at $1.85 per minute so if calling would work better I can give you that information; the interpreters go from French to English and English to French right on the phone with you via conference call.

Thank you for the questions and let me know if you have any more and we can work with you.

Best Regards,

Kimberly Wallace
Global Language Links LLC
Office: 248-283-0615
Fax: 877-800-9526
kwallace@globlanglinks.com
www.GlobLangLinks.com

From: Taylor, Michael [mailto:mltaylor@HDP.com]
Sent: Sunday, August 28, 2011 11:36 AM
To: Kimberly Wallace
Subject: Translation Quote Request (5074A-000013/REA)

Dear Kimberly,

I may have need of another English to French Translation.

What is the general "rush" turn around time and is there an additional cost for a rush order. All translations would be about 1/2 to 1 page.

I may also get communication in French from individuals that I would need rush translated to English.

Regards,

Michael

Michael L. Taylor
Patent Attorney

Office: 248.641.1600
Direct: 248.641.1289
Fax: 248.641.0270

HARNESS DICKEY

5445 Corporate Dr, Suite 200
Troy, MI 48098

IP Causes Worldwide

Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

ATTACHMENT D

Taylor, Michael

From: Taylor, Michael <mltaylor@HDP.com>
Sent: Tuesday, September 06, 2011 9:42 AM
To: Michel Scriban
Cc: Warner, Rick
Subject: RE: Re-issue of U.S. Patent 5,868,675 (5074a-000013/REA)

Dear Michel,

Thank you for confirming receipt of my previous email.

If everyone is able to return to us the executed declaration by the end of September, that is acceptable timing.

Did you believe that Dr Thiebaut or JF Uhl would be able to contact Dr. Henrion regarding the declaration?

The declaration is a formality of U.S. Patent Practice. It indicates that any corrected errors were not intentional. The previous declaration was to the same effect. Though you are not the direct authors (i.e. we drafted the claims) they are based on the original patent application of which all of you are the inventors, therefore you are the authors by extension.

The current assignee of the 5,868,675 patent is MEDTRONIC, INC. at 7000 CENTRAL AVENUE, N.E., MINNEAPOLIS, MINNESOTA 55432 assigned from Elekta IGS S.A.

I am not certain what you mean by "returns of this validation job." Once the Declarations are executed and filed, the patent should re-issue with the greater number of claims than the original patent and which we previously forwarded to you. The re-issued patent expire on the same date as the previous 5,868,675 patent.

Thank you,

Michael

HARNESS DICKEY
Michael L. Taylor | Patent Attorney
O | 248.641.1600 **D** | 248.641.1289 **F** | 248.641.0270
IP Causes Worldwide

From: Michel Scriban [mailto:m.scriban@nelixa.fr]
Sent: Monday, September 05, 2011 2:34 AM
To: Taylor, Michael
Subject: Re: Re-issue of U.S. Patent 5,568,675 (5074a-000013/REA)

Hello Michael,

Hope to be in Paris Mid-September and meet Dr Thiebaut coming back from vacation and perhaps JF Uhl...

Today, my question is why modifications need our signature as we are not the authors of the new claims. What returns can we expect of this validation job ? Who is now the "owner" of this patent ?

Thanks for your questions. I will transmit your answer to my collegues.

Best regards,

Le 31 août 2011 à 21:06, Taylor, Michael a écrit :

Dr. Scriban,

As we discussed yesterday, I am forwarding this email that discusses the U.S. Patent Application that is a reissue of the above referenced U.S. Patent and papers that we need executed. I am also copying each inventor for which we previously had an email address, Joel Henrion and Joel Francois Uhl. You indicated that you would forward this email to Jean-Baptiste Thiebaut, and also to Joel Henrion and Joel Francois Uhl if the email addresses we have for them are no longer correct. We previously had translated the below message that discusses the current process and our reason for contacting you. Also, if you have an email address for Jean-Baptiste Thiebaut, we would very much appreciate receiving it from you.

We very much appreciate your assistance in this matter. Please let us know any one of you will not be able to return the executed paper to us by October 3, 2011.

Comme vous pouvez vous en souvenir, vous avez été en contact avec Rick Warner ou Christopher Eusebi fin 2002 et début 2003 concernant une demande de redélivrance du brevet U.S. 5 568 675 (ci-joint). À ce moment-là, vous aviez exécuté une déclaration de redélivrance.

Lors de votre travail avec le bureau des brevets U.S. pour obtenir un brevet subventionnable, nous avons amendé les réclamations par celles jointes dans les « réclamations actuelles » ci-jointes, que nous vous soumettons pour révision. Selon les règles régissant les demandes de redélivrance, nous allons déposer une déclaration de redélivrance additionnelle. Nous avons joint une « déclaration de redélivrance additionnelle » pour votre exécution. Nous pensons qu'il s'agit du dernier document nécessaire pour cette demande. Une fois que le bureau des brevets U.S. reçoit ce document dûment exécuté, une redélivrance de brevet devrait être accordée. Un brevet redelivré remplace essentiellement le brevet d'origine.

Veuillez dûment exécuter la « déclaration de redélivrance additionnelle » et nous la renvoyer. Vous pouvez nous l'envoyer par courriel ou par fax. Si vous ne pouvez nous envoyer pas courriel ou par fax une copie dûment exécutée et devez envoyer une copie physique, nous pouvons vous donner un numéro de compte DHL pour couvrir le coût de l'envoi.

Dans le tableau ci-dessous, vous trouverez les coordonnées que nous avons pour chacun des inventeurs. Veuillez confirmer que ces informations sont exactes. Si vous pouviez également nous donner l'adresse courriel de Jean-Baptiste Thiebaut, nous en serions très reconnaissants.

Nous vous remercions d'avance pour votre aide et votre réponse rapide.

Name	DHL/Mailing Address	Email Address(es)	Phone
Michel Scriban	72 Chemin de Crapon 69360 Ternay, France	m.scriban@nelixa.fr	
Joel Henrion	17, Route de Chalone 51600 Suippes, France	Joel.henrion@wanadoo.fr	
Jean Francois UHL	199 avenue du Maine Paris, France 75014 *(auxiliary address- 12 rue Regard; 92380 Garche, France)*	Jf.uhl@free.fr Jf.uhl@wanadoo.fr	
Jean-Baptiste Thiebaut	42 boulevard Saint-Marcel Paris, France 75005		

Thank you and Best Regards,

Michael

Michael L. Taylor
Patent Attorney

Office: 248.641.1600
Direct: 248.641.1289
Fax: 248.641.0270

<att7e9cd.gif>

5445 Corporate Dr, Suite 200
Troy, MI 48098

IP Causes Worldwide

Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

<Supplemental Reissue declaration.PDF><US 5868675.PDF><Current Claims.DOC>

ATTACHMENT E

Taylor, Michael

From: Taylor, Michael
Sent: Wednesday, October 05, 2011 9:16 AM
To: 'Michel Scriban'
Cc: Jean-BaptisteTHIEBAUT Jean-BaptisteTHIEBAUT
Subject: RE: State of situation - Re: Re-issue of U.S. Patent 5,868,675 (5074a-000013/REA)

Importance: High

Dear Dr. Scriban,

Following is a French translation of a letter that we prepared in response to your email below. We appreciate your assistance in this matter.

Nous apprécions que vous ayez pris le temps et fait les démarches nécessaires pour contacter Dr. Uhl et Dr. Thiebaut. Nous espérons qu'ils vont bien. Nous supposons que tous les trois vous avez pu signer la déclaration pour redélivrance que nous vous avions transmise. Si c'est le cas, veuillez s'il-vous-plait me les envoyer, si possible par courriel.

Nous apprécions également vos efforts pour contacter Mr. Henrion. Veuillez nous prévenir dans le cas où vous ne seriez pas entré en contact avec Mr. Henrion avant le 18 octobre. Avez-vous une idée de la façon dont nous pourrions joindre Mr. Henrion ? La dernière adresse que vous avez pour lui est-elle :

17, Route de Chalone

51600 Suippes, France

et son adresse courriel : Joel.henrion@wanadoo.fr?

Notre société est un cabinet d'avocats qui représente Medtronic et Medtronic travaille actuellement à la redélivrance du brevet, inventé par vous et vos collègues, qui désormais leur appartient. Medtronic est maintenant le cessionnaire enregistré et le propriétaire de ce brevet. Vos signatures sur la déclaration de redélivrance sont pour indiquer que les erreurs corrigées par cette déclaration de redélivrance de brevet n'ont pas été commises avec l'intention de tromper de votre part. L'«erreur» a corriger est que les revendications ne sont pas aussi larges que ce qui avait été pensé au départ et que la revendication 14 se limitait à la visualisation endoscopique. Pour l'instant, Medtronic ne demande rien de plus que votre signature sur la déclaration de redélivrance pour faciliter l'acceptation de cette déclaration qui est basée

sur le brevet 5 868 675 sur lequel votre nom et ceux de vos collègues apparaissent.

Nous vous demandons simplement de confirmer que cette phrase dans la déclaration «Toute erreur dans le brevet qui a été corrigée dans cette demande de redélivrance et qui n'est pas couverte par le présent serment ou déclaration soumis à cette demande, s'est produite sans intention de tromper de la part de l'appliquant » est correcte et de signer cette déclaration. Cela signifie essentiellement que toutes les erreurs identifiées et corrigées par cette déclaration ont été faites sans intention de tromper. En d'autres termes, toutes les erreurs trouvées n'étaient pas destinées à tromper quelqu'un.

Si vous avez des questions, n'hésitez pas à nous en informer.

Best Regards,

Michael

HARNESS DICKEY

Michael L. Taylor | Patent Attorney
O | 248.641.1600 **D** | 248.641.1289 **F** | 248.641.0270
IP Causes Worldwide

From: Michel Scriban [mailto:m.scriban@nelixa.com]
Sent: Monday, October 03, 2011 6:12 AM
To: Taylor, Michael
Cc: Jean-BaptisteTHIEBAUT Jean-BaptisteTHIEBAUT
Subject: State of situation - Re: Re-issue of U.S. Patent 5,868,675 (5074a-000013/REA)

Bonjour,

Après un mois de septembre à l'emploi du temps extrêmement chargé pour tous et notamment le Dr Thiebaut, neurochirurgien, j'ai pu faire ce W.E. un point avec lui quant à votre demande apparu 8 ans après notre précédent contact.

Pas de pb pour avoir le Dr UHL mais cela n'est pas simple pour Mr Henrion avec qui on n'est pas en contact régulier depuis très longtemps (on cherche) et qui compte tenu de sa formation mathématique était au coeur des clés et algorithmes du brevet initial dont j'étais à l'époque en charge de la coordination.

La principale question qui reste en suspens pour tous pour ce brevet dont on a perdu le 'contrôle' et de comprendre quels sont les avantages (intellectuels, financiers,...) de notre signature voire les inconvénients et risques. Qu'attend Medtronic des auteurs ? Quel est le rôle de votre organisation ?

De plus à ce jour, nous n'avons aucun moyen de faire viser ces textes par un expert en brevet pour valider les prétentions que vous nous soumettez...

Voilà notre état d'esprit à ce jour,

A très bientôt

Michel SCRIBAN m.d.

E-Mail: m.scriban@nelixa.com

http://www.nelixa.com/

---------- Mail Address --------------
NelixA
Espace DMCI - 8ieme Et.
4 quai des Etroits,
F 69005 Lyon
France
Sec. Tel. +33 4 72 56 51 36

E-mail: contact@nelixa.com

Le 6 sept. 2011 à 15:41, Taylor, Michael a écrit :

Dear Michel,
Thank you for confirming receipt of my previous email.
If everyone is able to return to us the executed declaration by the end of September, that is acceptable timing.
Did you believe that Dr Thiebaut or JF Uhl would be able to contact Dr. Henrion regarding the declaration?
The declaration is a formality of U.S. Patent Practice. It indicates that any corrected errors were not intentional. The previous declaration was to the same effect. Though you are not the direct authors (i.e. we drafted the claims) they are based on the original patent application of which all of you are the inventors, therefore you are the authors by extension.
The current assignee of the 5,868,675 patent is MEDTRONIC, INC. at 7000 CENTRAL AVENUE, N.E., MINNEAPOLIS, MINNESOTA 55432 assigned from Elekta IGS S.A.
I am not certain what you mean by "returns of this validation job." Once the Declarations are executed and filed, the patent should re-issue with the greater number of claims than the original patent and which we previously forwarded to you. The re-issued patent expire on the same date as the previous 5,868,675 patent.
Thank you,
Michael

<att65c3e.gif>

Michael L. Taylor | Patent Attorney
O | 248.641.1600 **D** | 248.641.1289 **F** | 248.641.0270
IP Causes Worldwide

From: Michel Scriban [mailto:m.scriban@nelixa.fr]
Sent: Monday, September 05, 2011 2:34 AM
To: Taylor, Michael
Subject: Re: Re-issue of U.S. Patent 5,568,675 (5074a-000013/REA)

Hello Michael,

Hope to be in Paris Mid-September and meet Dr Thiebaut coming back from vacation and perhaps JF Uhl...

Today, my question is why modifications need our signature as we are not the authors of the new claims. What returns can we expect of this validation job ? Who is now the "owner" of this patent ?

Thanks for your questions. I will transmit your answer to my collegues.

Best regards,

Le 31 août 2011 à 21:06, Taylor, Michael a écrit :

Dr. Scriban,

As we discussed yesterday, I am forwarding this email that discusses the U.S. Patent Application that is a reissue of the above referenced U.S. Patent and papers that we need executed. I am also copying each inventor for which we previously had an email address, Joel Henrion and Joel Francois Uhl. You indicated that you would forward this email to Jean-Baptiste Thiebaut, and also to Joel Henrion and Joel Francois Uhl if the email addresses we have for them are no longer correct. We previously had translated the below message that discusses the current process and our reason for contacting you. Also, if you have an email address for Jean-Baptiste Thiebaut, we would very much appreciate receiving it from you.

We very much appreciate your assistance in this matter. Please let us know any one of you will not be able to return the executed paper to us by October 3, 2011.

Comme vous pouvez vous en souvenir, vous avez été en contact avec Rick Warner ou Christopher Eusebi fin 2002 et début 2003 concernant une demande de redélivrance du brevet U.S. 5 568 675 (ci-joint). À ce moment-là, vous aviez exécuté une déclaration de redélivrance.

Lors de votre travail avec le bureau des brevets U.S. pour obtenir un brevet subventionnable, nous avons amendé les réclamations par celles jointes dans les « réclamations actuelles » ci-jointes, que nous vous soumettons pour révision. Selon les règles régissant les demandes de redélivrance, nous allons déposer une déclaration de redélivrance additionnelle. Nous avons joint une « déclaration de redélivrance additionnelle » pour votre exécution. Nous pensons qu'il s'agit du dernier document nécessaire pour cette demande. Une fois que le bureau des brevets U.S. reçoit ce document dûment exécuté, une redélivrance de brevet devrait être accordée. Un brevet redelivré remplace essentiellement le brevet d'origine.

Veuillez dûment exécuter la « déclaration de redélivrance additionnelle » et nous la renvoyer. Vous pouvez nous l'envoyer par courriel ou par fax. Si vous ne pouvez nous envoyer pas courriel ou par fax une copie dûment exécutée et devez envoyer une copie physique, nous pouvons vous donner un numéro de compte DHL pour couvrir le coût de l'envoi.

Dans le tableau ci-dessous, vous trouverez les coordonnées que nous avons pour chacun des inventeurs. Veuillez confirmer que ces informations sont exactes. Si vous pouviez également nous donner l'adresse courriel de Jean-Baptiste Thiebaut, nous en serions très reconnaissants.

Nous vous remercions d'avance pour votre aide et votre réponse rapide.

Name	DHL/Mailing Address	Email Address(es)	Phone
Michel Scriban	72 Chemin de Crapon 69360 Ternay, France	m.scriban@nelixa.fr	
Joel Henrion	17, Route de Chalone 51600 Suippes, France	Joel.henrion@wanadoo.fr	
Jean Francois UHL	199 avenue du Maine Paris, France 75014 *(auxiliary address- 12 rue Regard; 92380 Garche, France)*	Jf.uhl@free.fr Jf.uhl@wanadoo.fr	

Jean-Baptiste Thiebaut	42 boulevard Saint-Marcel Paris, France 75005		

Thank you and Best Regards,

Michael

Michael L. Taylor
Patent Attorney

<att7e9cd.gif>

IP Causes Worldwide

Office: 248.641.1600
Direct: 248.641.1289
Fax: 248.641.0270

5445 Corporate Dr, Suite 200
Troy, MI 48098
Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

<Supplemental Reissue declaration.PDF><US 5868675.PDF><Current Claims.DOC>

ATTACHMENT F

Taylor, Michael

From: Taylor, Michael <mltaylor@HDP.com>
Sent: Tuesday, October 04, 2011 11:33 AM
To: globallanguagelinks@yahoo.com; kwallace@globlanglinks.com
Subject: English to French translation (5074A-000013/REA)

Kimberly,

We request that you translate the following into French by tomorrow morning [redacted] rush. Please confirm whether this is acceptable or not.

Language for Translation begins------

Dear Dr. Scriban,

We appreciate your effort in contacting Dr. Uhl and Dr. Thiebaut. We hope that they are doing well. We assume that all three of you have been able to execute the re-issue declaration that we previously forwarded to you. If so, please forward them to me, via email if possible.

We also appreciate your efforts in attempting to contact Mr. Henrion. Please let us now if you are unable to contact Mr. Henrion by October 18. Do you have any ideas where we could contact Mr. Henrion? Is the last best address you have for Mr. Henrion:

17, Route de Chalone

51600 Suippes, France

And email: Joel.henrion@wanadoo.fr

Our company is a law firm that represents Medtronic and Medtronic is current woring on the re-issue of the patent that they now own, which was originally invented by you and your co-inventors. Medtronic is now the recorded assignee and owner of this patent. Your signatures on the reissue declaration are to indicate that any errors corrected by this re-issue patent application were not done with any deceptive intent on your parts. The "error" to be corrected is that the claims are not as broad as could have originally been draft and that Claim 14 was limited to endoscopic viewing. As of right now, Medtronic asks no more than your signature on the re-issue declaration to expedite grant of this application which is based on the patent 5,868,675 on which you and your co-inventors are listed.

We simply ask that you confirm that statement in the declaration "Toute erreur dans le brevet qui a été corrigée dans cette demande de redélivrance et qui n'est pas couverte par le présent serment ou déclaration soumis à cette demande, s'est produite sans intention de tromper de la part de l'appliquant" is correct and execute the declaration. Essentially, any errors identified and corrected by these claims were made without deceptive intent. In other words, any identified errors were not intended to deceive anyone.

If you need any further clarification, please let us know.

Best Regards,

Michael

-----------language for translation ends

Thanks,

Michael

Michael L. Taylor | Patent Attorney
O|248.641.1600 **D**|248.641.1289 **F**|248.641.0270
5445 Corporate Dr, Suite 200, Troy, MI 48098

HARNESS DICKEY
IP Causes Worldwide Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

ATTACHMENT G

Taylor, Michael

From: Michel Scriban <m.scriban@nelixa.com>
Sent: Sunday, October 09, 2011 5:19 PM
To: Taylor, Michael
Subject: in progress - Re: Re-issue of U.S. Patent 5,868,675 (5074a-000013/REA)

Importance: High

Dear Michael,

As previous, this email will be continued in french because contains important terms.

Même si ce n'est pas aisé compte-tenu de l'emploi du temps très chargé des autres co-auteurs du brevet, nous avons pu nous concerter et nous entretenir ensemble quant à votre attente pressente de nous voir signer la version amendée du brevet.

Comme indiqué dans les précédents emails, une signature n'est pas un geste anodin qui engagent les signataires et auteurs. De plus, vérifier que l'essentiel est conforme aux revendications initiales et que - selon votre expression - vous n'avez pas introduit de "tromperie" va demander que nous étudions - avec l'aide d'experts - les documents soumis au regard des éléments mis au point il y a plus de 10 ans.

En nous sollicitant, cela rappelle aussi l'importance de ce brevet et les enjeux que nous avions anticipés à cette époque et observés depuis chez Medtronic ou autres industriels.

Sur le plan pratique, en première estimation, la valeur de l'intervention sera de 17 700 EUR à verser à chacun des 4 auteurs soit un total de 70 800 EUR hors frais de transfert et de sequestre auprès d'un avocat siégant en France et retenu par les deux parties.

Avant de préciser les modalités et affectations, nous vous prions de consulter le propriétaire de ce brevet dont nous quatre sommes les auteurs et de nous tenir informé de la suite.

En vous souhaitant bonne réception,

Best regards

For the team of the co-authors

Michel SCRIBAN m.d.

E-Mail: m.scriban@nelixa.com

Le 5 oct. 2011 à 15:15, Taylor, Michael a écrit :

Dear Dr. Scriban,

Following is a French translation of a letter that we prepared in response to your email below. We appreciate your assistance in this matter.

ATTACHMENT H

Dear Michael,

As previous, this email will be continued in French because contains important terms.

Although this was not easy because of the busy schedule of the other co-authors of the patent, we were able to meet and to talk about your expectations to see us sign the amended Patent.

As mentioned in previous emails, a signature is not insignificant and it commits the signatories and authors. Also, verifying that the summary is consistent with the original claims and that - as you say - you did not introduce a “deception" will require that we study - with the help of experts - the documents submitted with respect to the elements developed more than 10 years ago.

The fact that you are asking our signatures also emphasizes the importance of this patent and the issues that we had anticipated at that time and that have since been discovered at Medtronic and at other manufacturers.

In practical terms, as an initial estimate, the value of the intervention will be 17,700 EUR to be paid to each of the four authors for a total of 70,800 EUR excluding the fees for transfer and for sequestration by a lawyer based in France and retained by both parties.

Before specifying the terms and assignments, please consult the owner of this patent for which the four of us are the authors and keep us informed of the outcome.

Wishing you good reception,

ATTACHMENT I

HARNESS DICKEY

Michael L. Taylor
Direct Dial: 248-641-1289
mltaylor@hdp.com

COPY

October 31, 2011

VIA DHL and EMAIL

Waybill: 8809998164 -- Date: 2011-11-01 -- Pieces: 1/1 --
Description: BUSINESS DOCUMENTS -- Postcode: 75005, FRANCE --
Service: DOX -- Billing To: Sender -- Customs: NVD -- Shipment
Weight: 0.7 lb -- Discounted Total Charge: $30.90

Waybill: 8809998153 -- Date: 2011-11-01 -- Pieces: 1/1 --
Description: BUSINESS DOCUMENTS -- Postcode: 75014, FRANCE --
Service: DOX -- Billing To: Sender -- Customs: NVD -- Shipment
Weight: 0.7 lb -- Discounted Total Charge: $30.90

Waybill: 8809998142 -- Date: 2011-11-01 -- Pieces: 1/1 --
Description: BUSINESS DOCUMENTS -- Postcode: 51600, FRANCE --
Service: DOX -- Billing To: Sender -- Customs: NVD -- Shipment
Weight: 0.7 lb -- Discounted Total Charge: $30.90

Waybill: 8809998131 -- Date: 2011-11-01 -- Pieces: 1/1 --
Description: BUSINESS DOCUMENTS -- Postcode: 69360, FRANCE --
Service: DOX -- Billing To: Sender -- Customs: NVD -- Shipment
Weight: 0.7 lb -- Discounted Total Charge: $30.90

Sel 10/10

Michel Scriban
72 Chemin de Crapon
69360 Ternay, France
m.scriban@nelixa.fr

Joel Henrion
17, Route de Chalone
51600 Suippes, France
Joel.henrion@wanadoo.fr

Jean Francois UHL
199 avenue du Maine
Paris, France 75014
Jf.uhl@free.fr and Jf.uhl@wanadoo.fr

Jean-Baptiste Thiebaut
42 boulevard Saint-Marcel
Paris, France 75005
jbthiebaut@fo-rothschild.fr

Ref: OFFICE Date: 01Nov11
Dep: Michael L. Taylo Wgt: 1.00 LBS
DV: 0.00
SHIPPING: 9.92
SPECIAL: 1.44
HANDLING: 0.00
TOTAL: 11.36
Svcs: STANDARD OVERNIGHT
TRCK: 9061 5385 6883

Re: U.S. reissue application
Reissue of the U
Medtronic Ref. No. PCC
HDP Ref. No. 5074A-0C

Ref: OFFICE Date: 01Nov11
Dep: Michael L. Taylo Wgt: 1.00 LBS
DV: 0.00
SHIPPING: 9.92
SPECIAL: 1.44
HANDLING: 0.00
TOTAL: 11.36
Svcs: STANDARD OVERNIGHT
TRCK: 9061 5385 6872

Dear Inventors,

This communication is being provid

translation.

Ref: OFFICE Date: 01Nov11
Dep: Michael L. Taylo Wgt: 1.00 LBS
DV: 0.00
SHIPPING: 9.92
SPECIAL: 1.44
HANDLING: 0.00
TOTAL: 11.36
Svcs: STANDARD OVERNIGHT
TRCK: 9061 5385 6861

Ref: OFFICE Date: 01Nov11
Dep: Michael L. Taylo Wgt: 1.00 LBS
DV: 0.00
SHIPPING: 9.92
SPECIAL: 1.44
HANDLING: 0.00
TOTAL: 11.36
Svcs: STANDARD OVERNIGHT
TRCK: 9061 5385 6894

HARNESS DICKEY

Michael L. Taylor
Direct Dial: 248-641-1289
mltaylor@hdp.com

November 1, 2011

VIA DHL and EMAIL

Michel Scriban
72 Chemin de Crapon
69360 Ternay, France
m.scriban@nelixa.fr

Joel Henrion
17, Route de Chalone
51600 Suippes, France
Joel.henrion@wanadoo.fr

Jean Francois UHL
199 avenue du Maine
Paris, France 75014
Jf.uhl@free.fr and Jf.uhl@wanadoo.fr

Jean-Baptiste Thiebaut
42 boulevard Saint-Marcel
Paris, France 75005
jbthiebaut@fo-rothschild.fr

Re: U.S. reissue application 09/784,829 which is a
Reissue of the U.S. Patent 5,868,675
Medtronic Ref. No. PC0000173.06
HDP Ref. No. 5074A-000013/REA

Dear Inventors,

This communication is being provided in English followed by a French translation.

Medtronic, Inc. (herein Medtronic) hereby respectfully requests that each individual named as an inventor in the U.S. reissue application 09/784,829, including Michel Scriban, Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut, execute the previously provided Supplement Reissue Declaration and return it to Medtronic's representative Richard W. Warner at Harness, Dickey & Pierce promptly via email at rwarner@hdp.com or mail/courier to Harness Dickey, 5445 Corporate Dr, Suite 200, Troy, MI 48098 by **November 14, 2011**. For your convenience, we have provided pre-paid packages to return to us the executed Supplemental Reissue Declaration.

Medtronic has reviewed your letter of October 10, 2011 that requests payment of 70,800 EUR (about US$ 98,743.68) to all of the inventors for intervention, including execution of the previously provided Supplemental Reissue Declaration. Medtronic notes that no payment is required under the assignment agreement that was executed by all of the inventors on June 22, 1992 and deems your request for payment a refusal to execute and return the Supplemental Reissue Declaration. Medtronic would like to take this opportunity to fully explain why no payment is necessary and provide each of the inventors one final opportunity to execute and return to us the Supplemental Reissue Declaration.

An Assignment (Under Tab A) to Diadix S.A. that was executed by each of the inventors on June 22, 1992 states, "The undersigned hereby agree(s) to transfer a like interest, upon request of the said ASSIGNEE, its successors, assigns and legal representatives, and **without further remuneration**, in and to any and all divisions, continuations, substitutes, and **reissues** thereof; and to testify and **execute any**

papers for ASSIGNEE, its successors, assigns and legal representations, deemed essential by ASSIGNEE to ASSIGNEE'S full protection and title in and to the invention hereby transferred." Thus, Medtronic believes that executing further documents for reissue applications is a duty of each inventor upon Medtronic's request and should occur without further remuneration (i.e. payment).

The original U.S. Patent 5,868,675 was assigned from Diadix S.A. to Deemed International (executed on October 24, 1995), then from Deemed International to Elekta IGS S.A. (via a name change that was executed on August 14, 1997), and finally from Elekta IGS S.A. to Medtronic, Inc. (executed on December 14, 1999). Each of these Assignments is duly recorded in the United States Patent and Trademark Office in the U.S. Patent No. 5,868,675. The chain of title, as shown by the United States Patent and Trademark Office, is included under Tab B and can be viewed at http://assignments.uspto.gov/assignments/q?db=pat&qt=pat&reel=&frame=&pat=5868675. The subject application, to which the Supplement Reissue Declaration relates, is a reissue of the U.S. Patent 5,868,675. Accordingly, the Assignments of the U.S. Patent No, 5,868,675 are effective to the present reissue application. The duty of the inventors to execute further documents without further remuneration relating to reissues was transferred to Medtronic via the assignment chain enumerated above.

Further, Medtronic will take a refusal by each inventor to execute the Supplemental Reissue Declaration based upon non-receipt of payment as simply a refusal to execute the Supplemental Reissue Declaration. Medtronic can overcome this refusal by filing a petition with the United States Patent and Trademark Office

under 37 CFR §1.47. Upon acceptance of such a Petition, inventor signatures are no longer necessary in the reissue application.

Attached hereto (under Tab C) is a complete copy of the application as filed, the claims as pending, and the Supplemental Reissue Declaration. Medtronic against respectfully requests that each of the inventors execute the Supplemental Declaration and return it to Medtronic's Representative at Harness, Dickey & Pierce promptly via email at warner@hdp.com or mail/courier to Harness Dickey, 5445 Corporate Dr, Suite 200, Troy, MI 48098. If the Supplemental Reissue Declarations are not received by **November 14, 2011**, Medtronic will assume that each of the inventors has refused to execute the Supplemental Reissue Declaration and Medtronic will continue prosecuting the reissue application based upon the refusal of each of the inventors to execute the Supplemental Reissue Declaration.

Medtronic looks forward to your cooperation in this matter and requests that each inventor respond individually to this letter.

Beginning of French Translation

Le texte suivant est la traduction en français de la lettre ci-dessus.

Par la présente, Medtronic, Inc. (ci-après Medtronic) demande respectueusement que chaque individu désigné comme inventeur dans la demande de redélivrance U.S. 09/784,829, y compris Michel Scriban, Joel Henrion, Jean Francois UHL et Jean-Baptiste Thiebaut, signe la Déclaration supplémentaire pour redélivrance envoyée précédemment et la renvoie à Richard W. Warner, représentant de Medtronic

à Harness, Dickey & Pierce rapidement par email à rwarner@hdp.com ou par courrier à Harness Dickey, 5445 Corporate Dr, Suite 200, Troy, MI 48098 avant le **14 novembre 2011**. Pour votre commodité, nous vous envoyons des parquets prépayés à utiliser pour nous renvoyer la Déclaration supplémentaire pour redélivrance signée.

Medtronic a examiné votre lettre du 10 Octobre 2011 qui demande qu'un paiement de 70 800 euros (environ 98 743,68 $ américains) soit versé à tous les inventeurs pour leur intervention, y compris l'exécution de la Déclaration supplémentaire pour redélivrance envoyée précédemment. Medtronic note qu'aucun paiement n'est requis en vertu de l'accord de cession qui a été exécuté par tous les inventeurs le 22 juin 1992 et juge votre demande de paiement comme un refus de signer et de renvoyer la Déclaration supplémentaire pour redélivrance. Medtronic voudrait profiter de cette occasion pour expliquer en détail pourquoi aucun paiement n'est nécessaire et offrir à chacun des inventeurs une ultime occasion de signer et de nous renvoyer la Déclaration supplémentaire pour redélivrance.

Une cession à Diadix SA (sous l'onglet A), exécutée par chacun des inventeurs le 22 juin 1992, stipule : « Par la présente, les soussignés acceptent de transférer un tel intérêt à la demande dudit CESSIONNAIRE, ses ayants droit et représentants légaux, et **sans autre rémunération**, dans et pour une ou toutes les divisions, les continuations, les substituts et les rééditions de celui-ci ; et de certifier et d'exécuter **tous les papiers** pour le CESSIONNAIRE, ses ayants droit et représentants juridiques, jugés essentielles par le CESSIONNAIRE à la protection du CONCESSIONNAIRE et de son titre de propriété et de l'invention transférés par les présentes. » Ainsi,

Medtronic estime que l'exécution de documents supplémentaires pour les demandes de redélivrance est un devoir de chaque inventeur à la demande de Medtronic et devrait être accompli sans rémunération (paiement par exemple).

Le brevet américain 5 868 675 d'origine a été cédé par Diadix SA à Deemed International (exécuté le 24 octobre 1995), puis par Deemed International à Elekta IGS S.A. (via un changement de nom exécuté le 14 août 1997), et enfin par Elekta IGS S.A. à Medtronic, Inc (exécuté le 14 décembre 1999). Chacune de ces cessions est dûment enregistrée au «United States Patent and Trademark Office» (Bureau des brevets et des marques des États-Unis) dans le brevet américain N°. 5 868 675. La chaîne du titre, comme donnée par le «United States Patent and Trademark Office», est incluse sous l'onglet B et peut être consultée à http://assignments.uspto.gov/assignments/q?db=pat&qt=pat&reel=&frame=&pat=5868675. La demande en question, à laquelle la Déclaration supplémentaire pour redélivrance est rattachée, est une réédition du brevet américain 5 868 675. En conséquence, les cessions du brevet américain No. 5 868 675 restent en vigueur pour cette demande de redélivrance. Le devoir des inventeurs de signer des documents supplémentaires sans rémunération additionnelle concernant les rééditions a été transféré à Medtronic par la chaîne de cessions ci-dessus énumérée.

De plus, Medtronic considérera un refus par chaque inventeur d'exécuter la Déclaration supplémentaire pour redélivrance basée sur la non-réception du paiement comme un simple refus d'exécuter la Déclaration supplémentaire pour redélivrance. Medtronic peut surmonter ce refus en déposant une requête auprès du «United States

Patent and Trademark Office» sous l'article 37 CFR § 1.47. Dès l'acceptation d'une telle pétition, les signatures des inventeurs ne seront plus nécessaires à la demande de redélivrance.

Ci-joint (sous l'onglet C) est une copie complète de la demande déposée, les revendications en attente et la Déclaration supplémentaire pour redélivrance. Medtronic demande à nouveau respectueusement que chacun des inventeurs exécute la Supplemental Declaration et la renvoie au représentant de Medtronic à Harness, Dickey & Pierce rapidement par email à warner@hdp.com ou par courrier à Harness, Dickey, 5445 Corporate Dr, Suite 200, Troy, MI 48098. Si les Déclaration supplémentaire pour redélivrance ne sont pas reçues avant le 14 novembre 2011, Medtronic supposera que chacun des inventeurs a refusé d'exécuter la Déclaration supplémentaire pour redélivrance et Medtronic continuera de poursuivre les demandes de redélivrance en utilisant le refus de chacun des inventeurs d'exécuter les Déclaration supplémentaire pour redélivrance.

Medtronic se réjouit de votre coopération dans cette affaire et demande que chaque inventeur réponde individuellement à cette lettre.

Best Regards,

Michael L. Taylor

Richard W. Warner

16367800.1

NOVEMBER 1, 2011 LETTER

ATTACHMENT 1

Sole or Joint USA Patent Appln. For inventions made outside USA

ASSIGNMENT

In consideration of the sum of One Dollar ($1.00) and other good and valuable consideration paid to each of the undersigned, to wit:

Insert Name(s) of Inventor(s)

(1) Joël HENRION (5) ____
(2) Michel SCRIBAN (6) ____
(3) Jean-Baptiste THIEBAUT (7) ____
(4) Jean-François UHL (8) ____

the receipt and sufficiency of which are hereby acknowledged by the undersigned who at the behest of, hereby sell(s), assign(s) and transfer(s) unto,

Insert Name of Assignee Address

DIADIX S.A. c/o AZAR S.A.
4 place de la Concorde - 75008 PARIS / FRANCE

(hereinafter designated "ASSIGNEE") the entire right, title and interest for the United States of America as defined in 35 U.S.C. 100, in the invention known as

Title of Invention

LOCAL INTERVENTION INTERACTIVE SYSTEM INSIDE A REGION OF A NON HOMOGENEOUS STRUCTURE

for which an application for Letters Patent of the United States of America has been executed even date herewith by the undersigned, and the undersigned hereby authorize(s) and request(s) the United States Commissioner of Patents and Trademark to issue said Letters Patent to the said ASSIGNEE, for its interest as ASSIGNEE, its successors, assigns and legal representatives; the undersigned agree(s) that the attorneys of record in said application shall hereafter act on behalf of said ASSIGNEE;

AND the undersigned hereby agree(s) to transfer a like interest, upon request of the said ASSIGNEE, its successors, assigns and legal representatives, and without further remuneration, in and to any and all divisions, continuations, substitutes, and reissues thereof; and to testify and execute any papers for ASSIGNEE, its successors, assigns and legal representatives, deemed essential by ASSIGNEE to ASSIGNEE'S full protection and title in and to the invention hereby transferred.

Please sign concurrently with application, Signed on the date(s) indicated beside my/our signature(s).

RECORDED
PATENT AND TRADEMARK OFFICE

INVENTOR(S)	DATE SIGNED	WITNESS(ES)
1) Name: Joël HENRION	JUL 22 1992	Eric LE FORESTIER
2) Name: Michel SCRIBAN		
3) Name: Jean-Baptiste THIEBAUT		
4) Name: Jean-François UHL		
5) Name:		
6) Name:		
7) Name:		
8) Name:		

REEL 6370 FRAME 0313

NOVEMBER 1, 2011 LETTER

ATTACHMENT 2

Patent Assignment Abstract of Title

NOTE:Results display only for issued patents and published applications. For pending or abandoned applications please consult USPTO staff.

Total Assignments: 4

Patent #: 5868675 **Issue Dt:** 02/09/1999 **Application #:** 07847059 **Filing Dt:** 06/22/1992

Inventors: JOEL HENRION, MICHEL SCRIBAN, JEAN-BAPTISTE THIEBAUT, JEAN-FRANCOIS UHL

Title: INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHOMOGENEOUS STRUCTURE

Assignment: 1

Reel/Frame: 006370/0812 **Recorded:** 06/22/1992 **Pages:** 2

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST.

Assignors: HENRION, JOEL **Exec Dt:** 06/22/1992
SCRIBAN, MICHEL **Exec Dt:** 06/22/1992
THIEBAUT, JEAN-BAPTISTE **Exec Dt:** 06/22/1992
UHL, JEAN-FRANCOIS **Exec Dt:** 06/22/1992

Assignee: DIADIX S.A.
C/O AZAR S.A. 4 PLACE DE LA CONCORDE
75008 PARIS, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN
12400 WILSHIRE BOULEVARD
SEVENTH FLOOR
WEST LOS ANGELES, CA 90025
ATTN: ERIC S. HYMAN

Assignment: 2

Reel/Frame: 007785/0285 **Recorded:** 01/29/1996 **Pages:** 2

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

Assignor: DIADIX S.A. **Exec Dt:** 10/24/1995

Assignee: DEEMED INTERNATIONAL
2 AV. DE VIGNATE - CENTRE EQUATION, 38610
GIERES, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR ET AL.
ERIC S. HYMAN
12400 WILSHIRE BLVD.
SEVENTH FLOOR
LOS ANGELES, CA 90025

Assignment: 3

Reel/Frame: 009390/0742 **Recorded:** 08/17/1998 **Pages:** 5

Conveyance: CHANGE OF NAME (SEE DOCUMENT FOR DETAILS).

Assignor: DEEMED INTERNATIONAL **Exec Dt:** 08/14/1997

Assignee: ELEKTA IGS S.A.
2, AVENUE DE VIGNATE
BATIMENT 5 38610 GIERES, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN
ERIC S. HYMAN
12400 WILSHIRE BOULEVARD
SEVENTH FLOOR

LOS ANGELES, CA 90025

Assignment: 4

Reel/Frame: 014384/0001 **Recorded:** 02/24/2003 **Pages:** 5

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

Assignor: ELEKTA IGS S.A. **Exec Dt:** 12/14/1999

Assignee: MEDTRONIC, INC.
7000 CENTRAL AVENUE, N.E.
MINNEAPOLIS, MINNESOTA 55432

Correspondent: HARNESS, DICKEY & PIERCE, P.L.C.
STEPHEN J. FOSS
P.O. BOX 828
BLOOMFIELD HILLS, MI 48303

NOVEMBER 1, 2011 LETTER

ATTACHMENT 3

English	French
SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)	DÉCLARATON SUPPLÉMENTAIRE POUR REDÉLIVRANCE D'UNE DEMNADE DE BREVET POUR CORRIGER DES « ERREURS » (37 CFR 1.175)
Attorney Docket: 5074A-000013/REA First Named Inventor: Jean Francois Uhl Application Number: 09/784,829 Filing Date: February 8, 2001 Art Unit: 3737 Examiner Name: Ruth S. Smith	Numéro de registre: 5074A-000013/REA Nom du premier inventeur: Jean Francois Uhl Numéro de l'application: 09/784,829 Date de dépôt: 8 février 2001 Unité d'art : 3737 Nom de l'examinateur: Ruth S. Smith
I/We hereby declare that: **Every error in the patent which was corrected in the present reissue application, and which is not covered by the prior oath(s) and/or declaration(s) submitted in this application, arose without any deceptive intention on the part of the applicant.** **WARNING:** **Petitioner/applicant is cautioned to avoid submitting personal information in documents files in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO.** **Petitioner/application is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.** **I/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.**	**Je(nous) déclare(ons) que :** **Toute erreur dans le brevet qui a été corrigée dans cette demande de redélivrance et qui n'est pas couverte par le présent serment ou déclaration soumis à cette demande, s'est produite sans intention de tromper de la part de l'appliquant.** **AVERTISSEMENT :** **Le requérant / demandeur est mis en garde contre la soumission de renseignements personnels dans les documents déposés dans une demande de brevet qui peuvent aider à l'usurpation d'identité. Les renseignements personnels tels que numéros de sécurité sociale, numéros de compte bancaire, ou numéros de carte de crédit (autre qu'un chèque ou un formulaire d'autorisation de carte de crédit PTO-2038 dans le but de faire un paiement) ne sont jamais requis par l'USPTO (Bureau des brevets des États-Unis) pour appuyer une pétition ou une demande. Si ce type de renseignements personnels est inclus dans les documents déposés à l'USPTO, les demandeurs / requérants devraient envisager de les enlever des documents avant de les soumettre à l'USPTO.** **Le requérant / demandeur est informé que le dossier de demande de brevet est à la disposition du public après la publication de la demande (sauf si une demande de non-publication en conformité avec 37 CFR 1.213 (a) a été faite dans cette demande) ou après la délivrance d'un brevet. En outre, le dossier d'une demande abandonnée peut également être mis à la disposition du public si la demande est référencée dans une application publiée ou un brevet délivré (voir 37 CFR 1.14). Les chèques et formulaires d'autorisation de carte de crédit PTO-2038 soumis pour fins de paiement ne sont pas conservés dans le dossier de demande et ne sont donc pas accessibles au public.** **Je / Nous déclarons que toutes les déclarations faites selon ma/notre connaissance dans ce document sont véridiques et que toutes les déclarations faites sur des informations et croyances sont considérées comme vraies. De plus, ces déclarations ont été faites en sachant que toute fausse déclaration volontaire est passible d'une amende ou d'une peine d'emprisonnement, ou les deux, en vertu de la loi 18 USC 1001 et que de telles déclarations risquent de compromettre la validité de la demande ou d'un brevet délivré à partir de celle-ci.**
Name of First Inventor: Jean Francois Uhl Inventor's Signature ________________ Date __________________	Nom du premier inventeur: Jean Francois Uhl Signature de l'inventeur ________________ Date ____________________
Name of Second Inventor: Joel Henrion Inventor's Signature________________ Date________________	Nom du deuxième inventeur : Joel Henrion Signature de l'inventeur ________________ Date ____________________
Name of Third Inventor: Michel Scriban Inventor's Signature ________________ Date ________________	Nom du troisième inventeur : Michel Scriban Signature de l'inventeur ________________ Date ____________________
Name of Fourth Inventor: Jean-Baptiste Thiebaut Inventor's Signature ________________ Date________________	Nom du quatrième inventeur : Jean-Baptiste Thiebaut Signature de l'inventeur ________________ Date ____________________

US005868675A

United States Patent [19]

Henrion et al.

[11] **Patent Number: 5,868,675**

[45] **Date of Patent: *Feb. 9, 1999**

[54] **INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE**

[75] Inventors: **Joël Henrion**, Suippes; **Michel Scriban**, Ternay; **Jean-Baptiste Thiebaut**; **Jean-François Uhl**, both of Paris, all of France

[73] Assignee: **Elekta IGS S.A.**, Gieres, France

[*] Notice: The terminal 36 months of this patent has been disclaimed.

[21] Appl. No.: **847,059**

[22] PCT Filed: **May 10, 1990**

[86] PCT No.: **PCT/FR90/00714**

§ 371 Date: **Jun. 22, 1992**

§ 102(e) Date: **Jun. 22, 1992**

[87] PCT Pub. No.: **WO91/04710**

PCT Pub. Date: **Apr. 18, 1991**

[30] **Foreign Application Priority Data**

Oct. 5, 1989 [FR] France 89 13028

[51] **Int. Cl.**^{6} **A61B 5/05**

[52] **U.S. Cl.** **600/424**; 606/130

[58] **Field of Search** 128/653.1; 378/4, 378/20, 41, 58, 205; 606/130; 901/6, 16, 41; 600/407, 411, 415, 417, 424

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,638,798	1/1987	Shelden et al.	606/130
4,791,934	12/1988	Brunnett	128/653.1
5,050,608	9/1991	Watanabe et al.	128/653.1
5,078,140	1/1992	Kwoh	128/653.1
5,143,076	9/1992	Hardy et al.	606/130
5,186,174	2/1993	Schlöndorff et al.	128/653.1
5,273,039	12/1993	Fujiwara et al.	600/407
5,280,427	1/1994	Magnusson et al.	606/130
5,285,787	2/1994	Machida	606/130
5,409,497	4/1995	Siczek et al.	606/130
5,572,999	11/1996	Fubda et al.	600/407

FOREIGN PATENT DOCUMENTS

0009151	12/1988	WIPO .
WO 88/09151	12/1988	WIPO .

OTHER PUBLICATIONS

Lavallee, S. A New System for Computer Assisted Neurosurgery. IEEE Engineering in Medicine & Biology Society 11th Annual International Conference, vol. 11, pp. 926–927, Nov. 1989.

Watanabe, E et al. Three–Dimenstional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotaxic Surgery. Surg. Neurol., vol. 27, pp. 543–547, 1987.

(List continued on next page.)

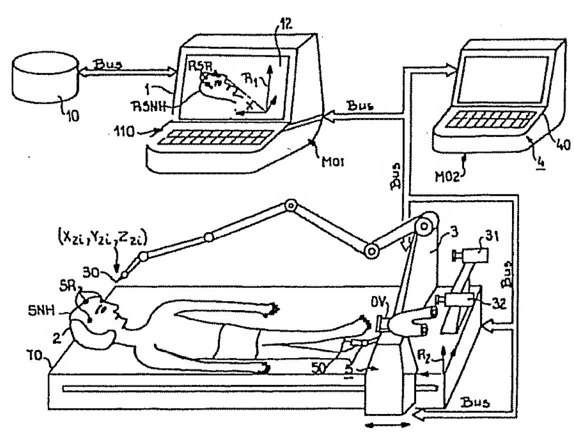
Primary Examiner—Brian Casler

Attorney, Agent, or Firm—Blakely Sokoloff Taylor & Zafman

[57] **ABSTRACT**

An interactive system for a local intervention inside a region of a non-homogeneous structure, such as the skull of a patient, which is related to the frame of reference (R_2) of an operation table, and which is connected to a reference structure comprising a plurality of base points. The system creates on a screen a representation of the non-homogeneous structure and of the reference structure connected thereto, provides the coordinates of the images of the base points in the first frame of reference (R_1), allows the marking of the coordinates of the base points in R_2, and allows the carrying out of the local intervention with an active member such as a trephining tool, a needle, or a radioactive or chemical implant. The systems also optimizes the transfer of reference frames between R_1 and R_2, from the coordinates of the base points in R_2 and the images in R_1 by reducing down to a minimum the deviations between the coordinates of images in R_1 and the base points in R_1 after transfer. The system also establishes real time bi-directional coupling between: (1) an origin and a direction of intervention simulated on the screen, (2) the position of the active member.

16 Claims, 13 Drawing Sheets



OTHER PUBLICATIONS

Batnitzky, S. et al. Three–Dimensional Computer Reconstruction from Surface Contours for Head CT Examinations. J. Comp. Asst. Tomogr., vol. 5, No. 1, pp. 60–67, Feb. 1981.

Roberts, D.W., et al. A Frameless Stereotaxic Integration of Computerized Tomographic Imaging and the Operating Microscope. J. Neurosurg., vol. 65, pp. 545–549, 1986.

Kelly, P.J. et al. Computer–assisted Stereotactic Laser Microsurgery for the Treatment of Intracranial Neoplasms, Neurosurgery. vol. 10, No. 3, pp. 324–330, 1982.

S. Lavallee, "A New System for Computer Neurosurgery", IEEE Eng. in Medicine & Bio. Soc. 11th Annual Int. Conf., Nov. 9–12, 1989, pp. 926–927.

Watanabe et al., Three Dimensional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotoxic Surgery, Surg. Neurol., 1987, No. 27, pp. 543–547.

P.J. Kelly et al., "Computer–Assisted Stereotactic Laser Micro–Surgery for the Treatment of Intracranial Neoplasms", Neuro., vol. 10, No. 3, 1982, pp. 324–330.

Batnitzky et al., "Three–dimensional Computer Reconstruction From Surface Contours for Head CT Examinations", Journal of Comp. Assisted Tomography, No. 5, Feb. 1981, pp. 60–67

Roberts et al., "A Frameless Stereotoxic Integration of Computerized Tomographic Imaging and the Operating Microsc gsl", J. of Neuro. Surg. No. 65, 1986, pp. 545–549.

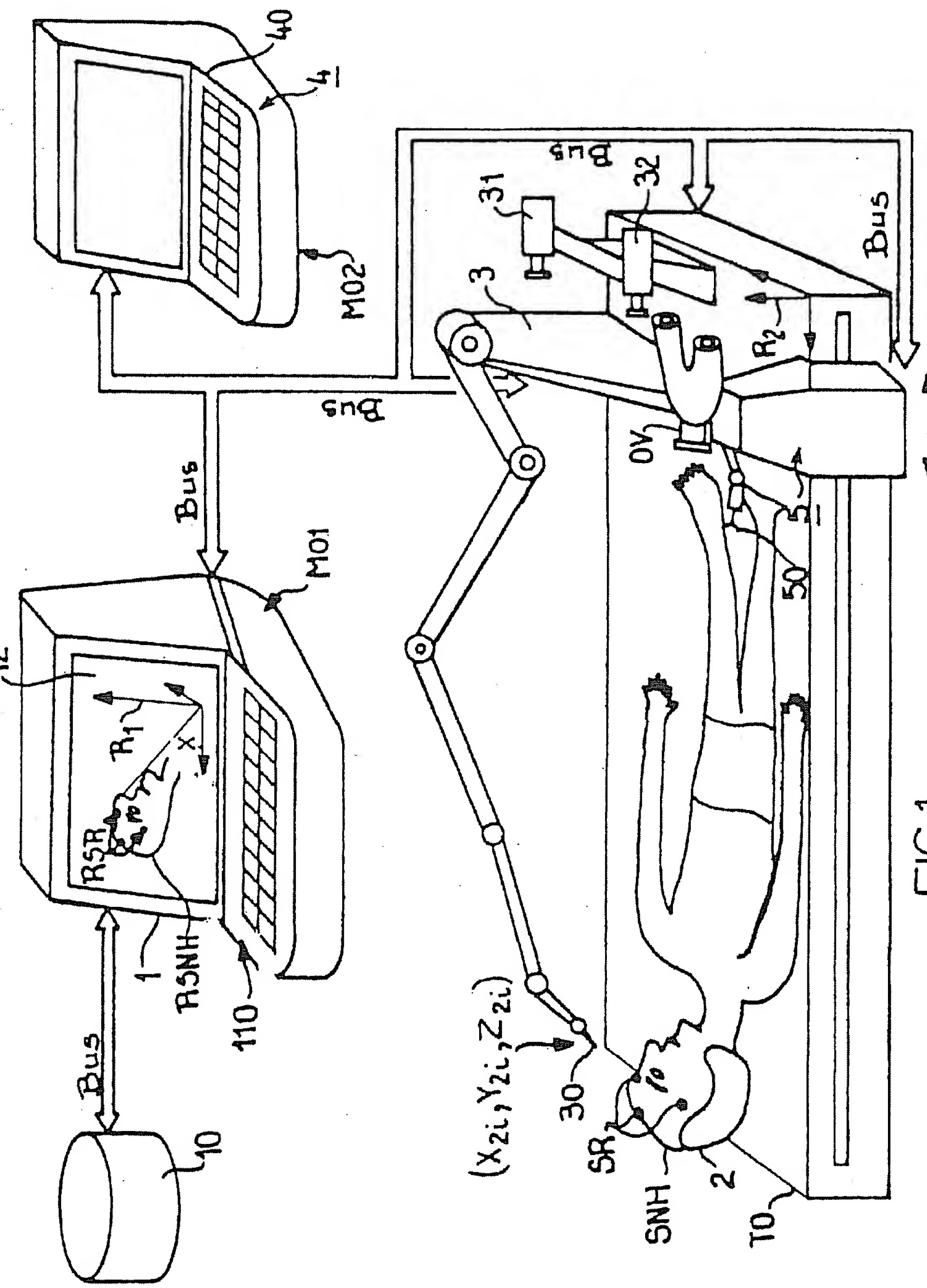

40
4
M02
Bus
31
32
3
Bus
R2
Bus
OV
5
50
12
R1
X
RSR
RSNH
1
110
M01
Bus
10
Bus
(X2i,Y2i,Z2i)
30
SR
SNH
2
TO

FIG_1

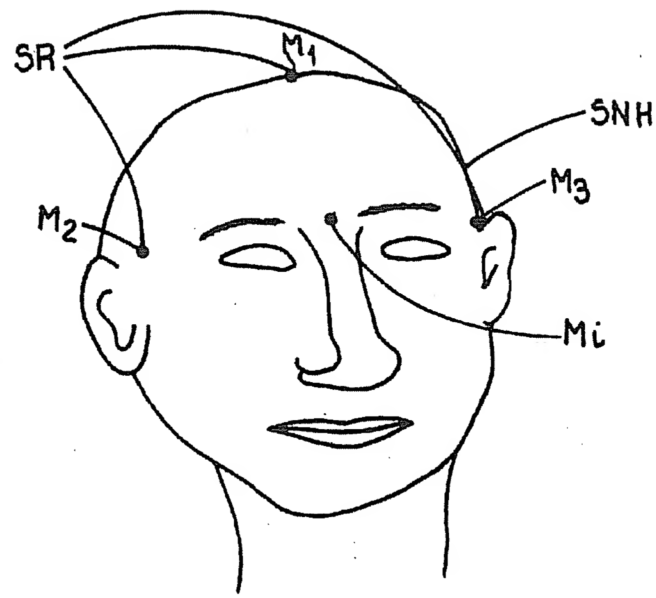


FIG_2

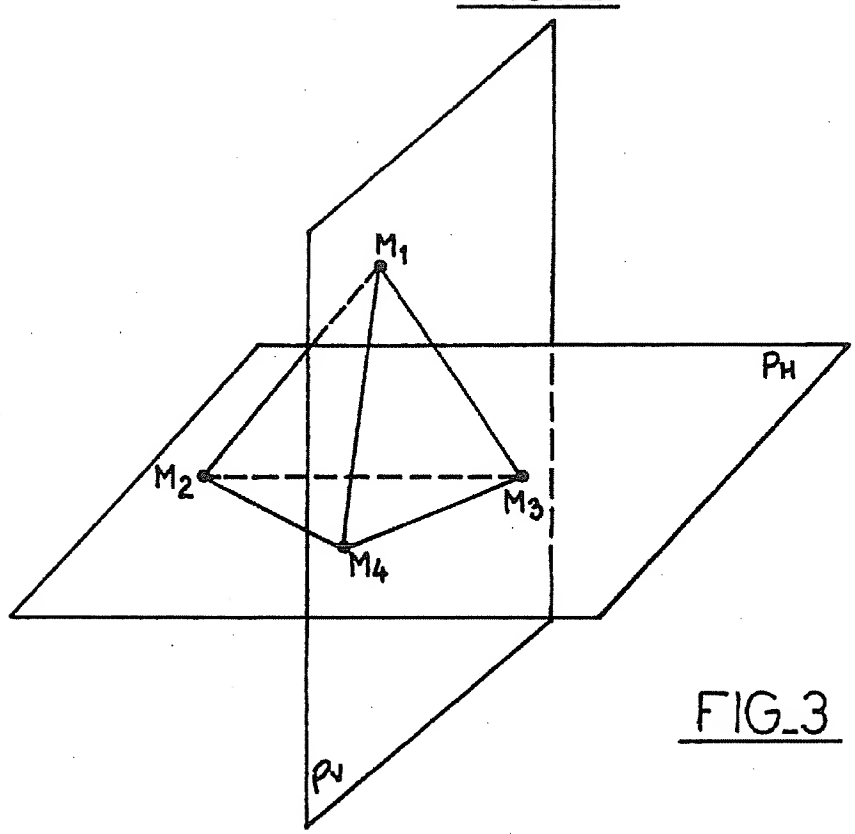


FIG_3

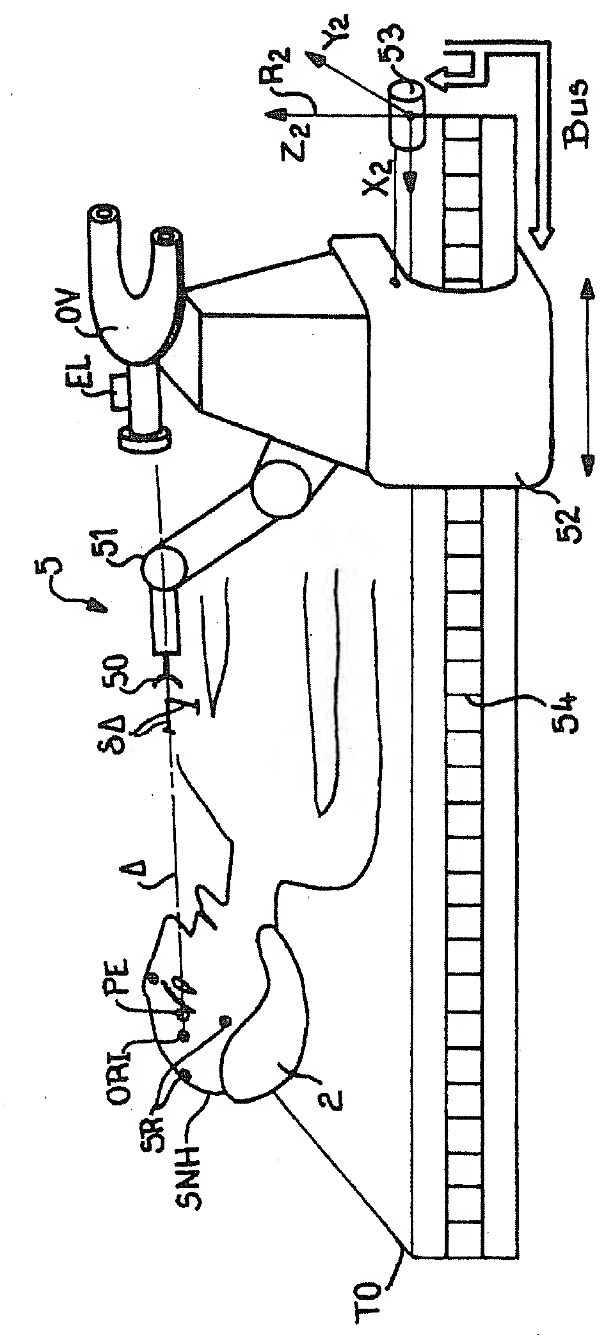


FIG. 4

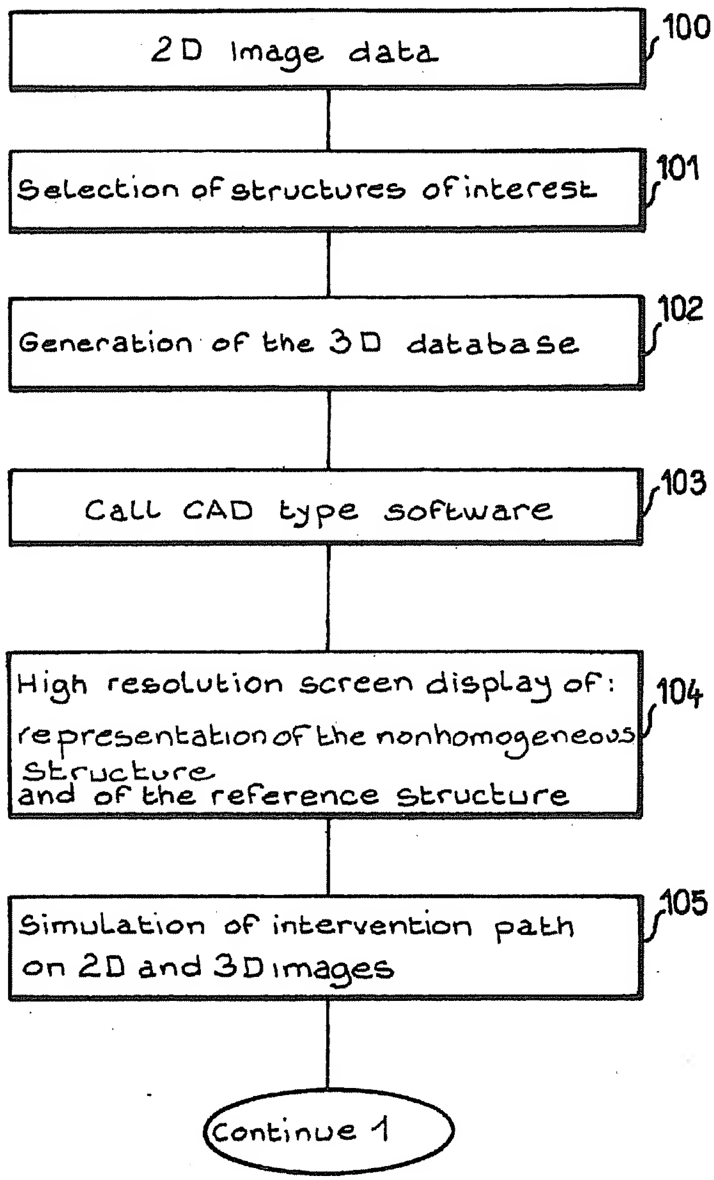

2D Image data
100
Selection of structures of interest
101
Generation of the 3D database
102
Call CAD type software
103
High resolution screen display of:
representation of the nonhomogeneous structure
and of the reference structure
104
Simulation of intervention path
on 2D and 3D images
105
Continue 1

FIG_5a

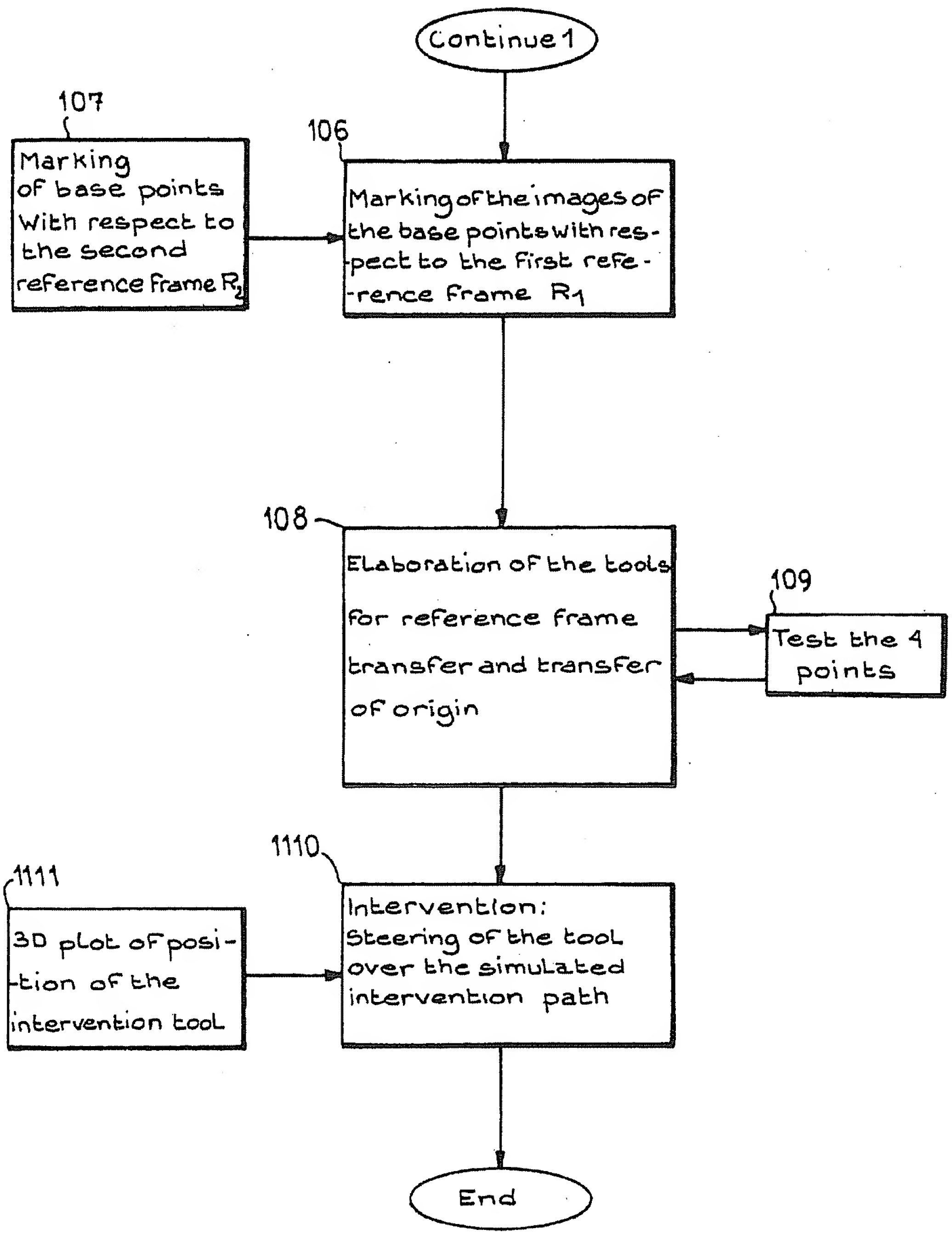

Continue 1
107
Marking of base points With respect to the second reference frame R2
106
Marking of the images of the base points with respect to the first reference frame R1
108
Elaboration of the tools for reference frame transfer and transfer of origin
109
Test the 4 points
1110
1111
3D plot of position of the intervention tool
Intervention: Steering of the tool over the simulated intervention path
End

FIG_5b

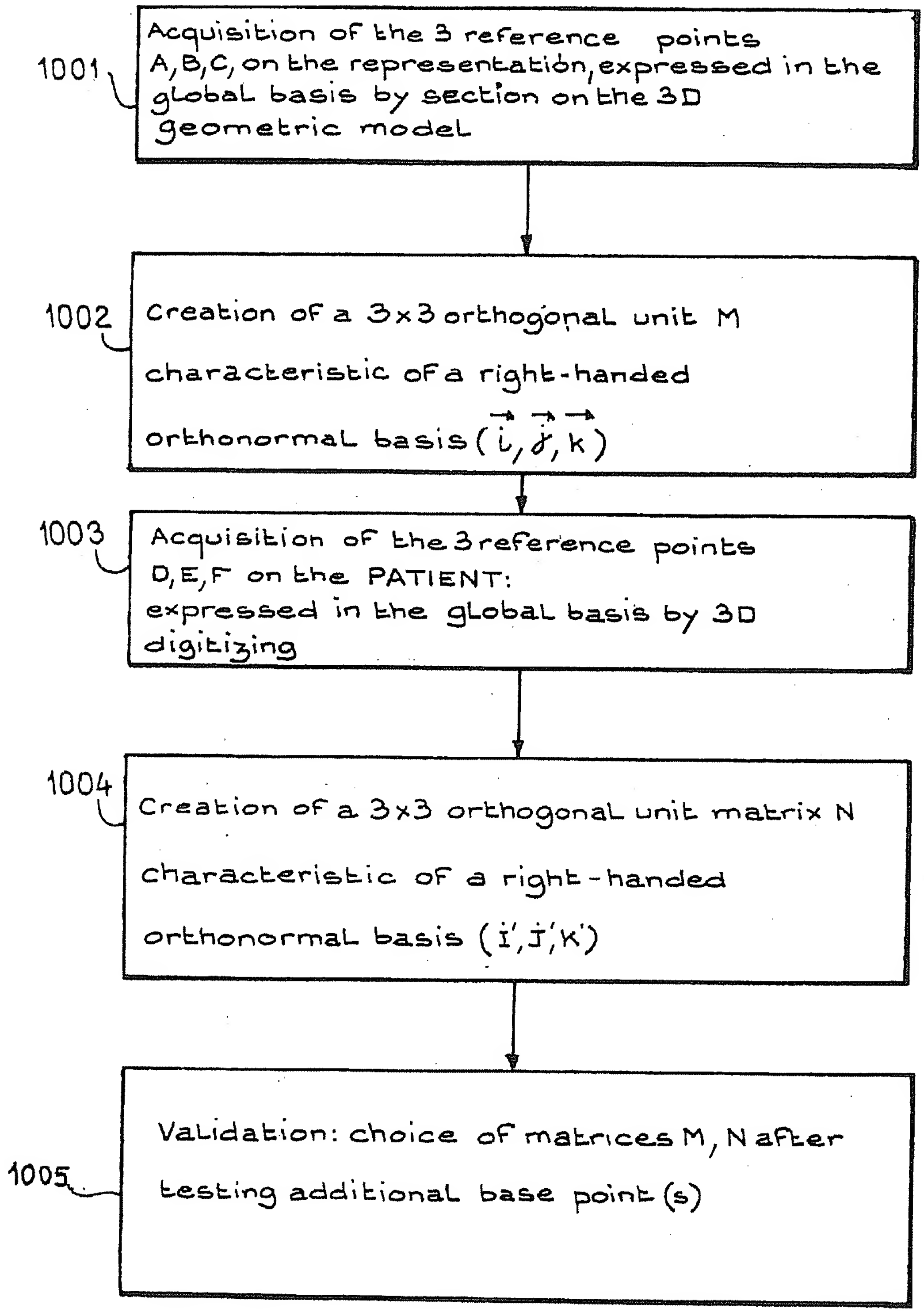

1001
Acquisition of the 3 reference points A, B, C, on the representation, expressed in the global basis by section on the 3D geometric model
1002
Creation of a 3x3 orthogonal unit M characteristic of a right-handed orthonormal basis ($\vec{i}, \vec{j}, \vec{k}$)
1003
Acquisition of the 3 reference points D, E, F on the PATIENT: expressed in the global basis by 3D digitizing
1004
Creation of a 3x3 orthogonal unit matrix N characteristic of a right-handed orthonormal basis (i', j', k')
1005
Validation: choice of matrices M, N after testing additional base point (s)

FIG 6

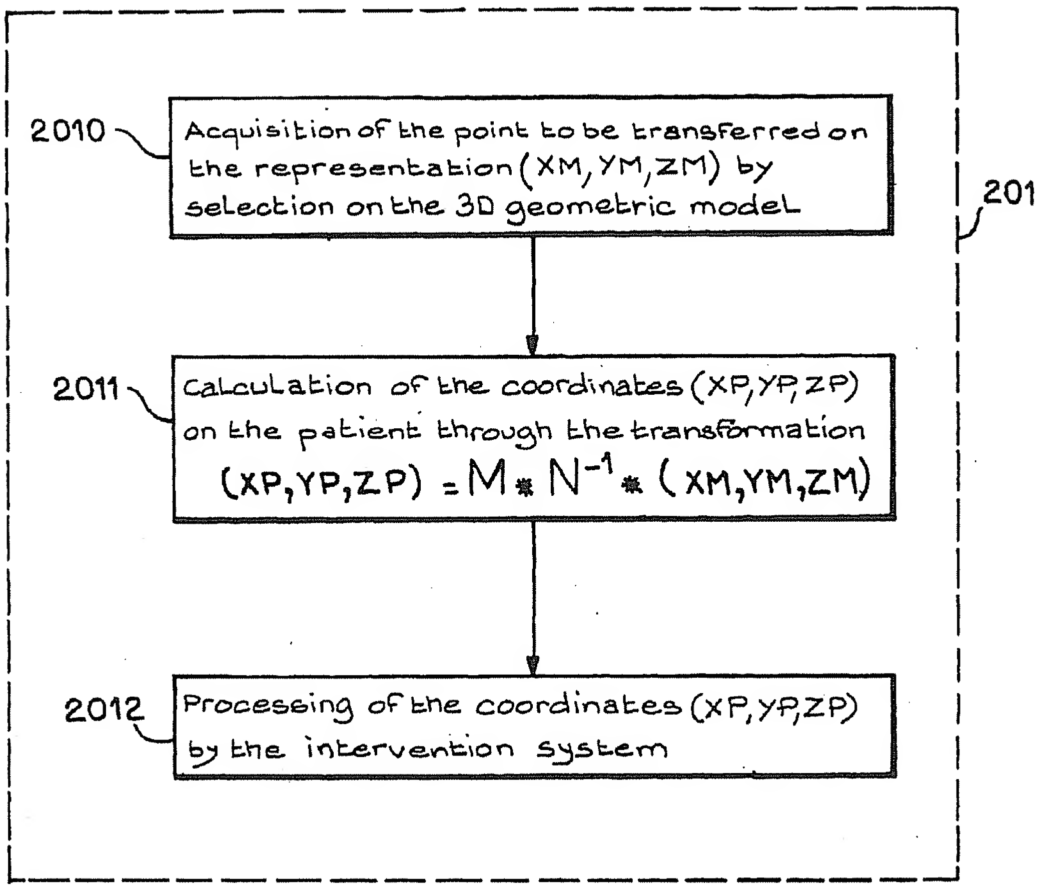

2010
Acquisition of the point to be transferred on the representation (XM, YM, ZM) by selection on the 3D geometric model
201
2011
Calculation of the coordinates (XP, YP, ZP) on the patient through the transformation
(XP, YP, ZP) = M * N^-1 * (XM, YM, ZM)
2012
Processing of the coordinates (XP, YP, ZP) by the intervention system

FIG. 7

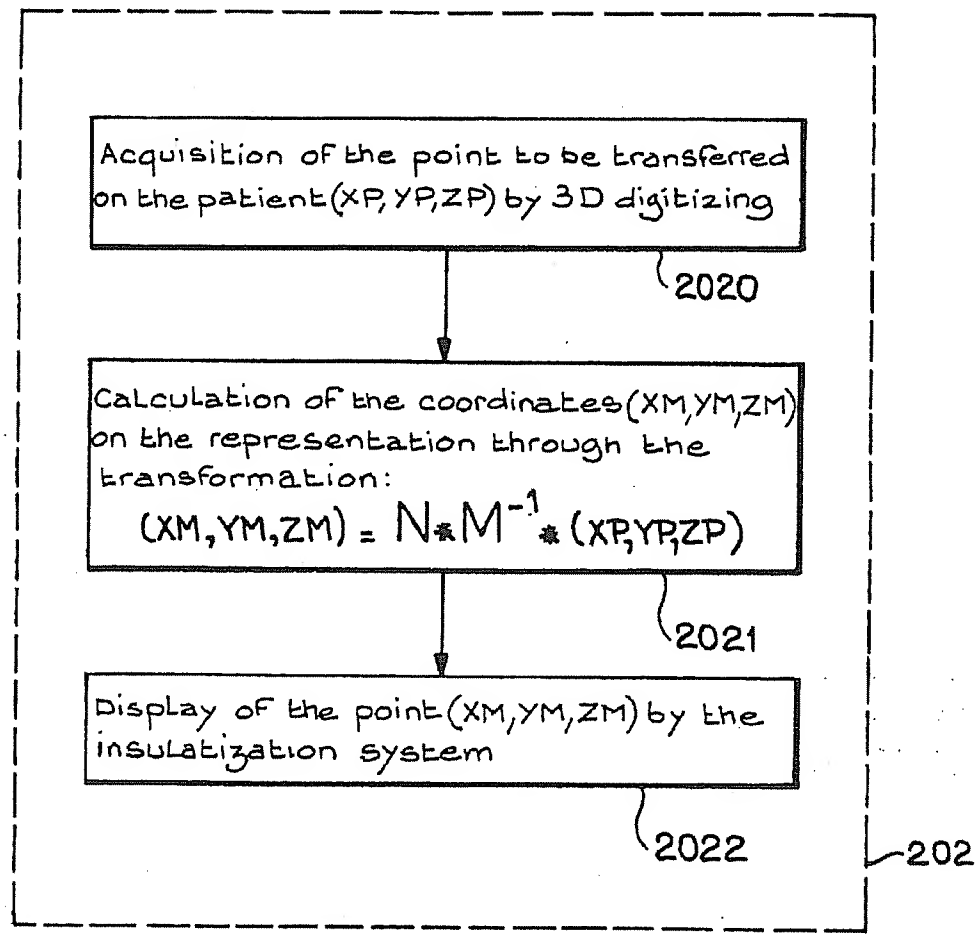

Acquisition of the point to be transferred on the patient (XP, YP, ZP) by 3D digitizing
2020
Calculation of the coordinates (XM, YM, ZM) on the representation through the transformation:
(XM, YM, ZM) = N*M⁻¹*(XP, YP, ZP)
2021
Display of the point (XM, YM, ZM) by the insulatization system
2022
202

FIG_8

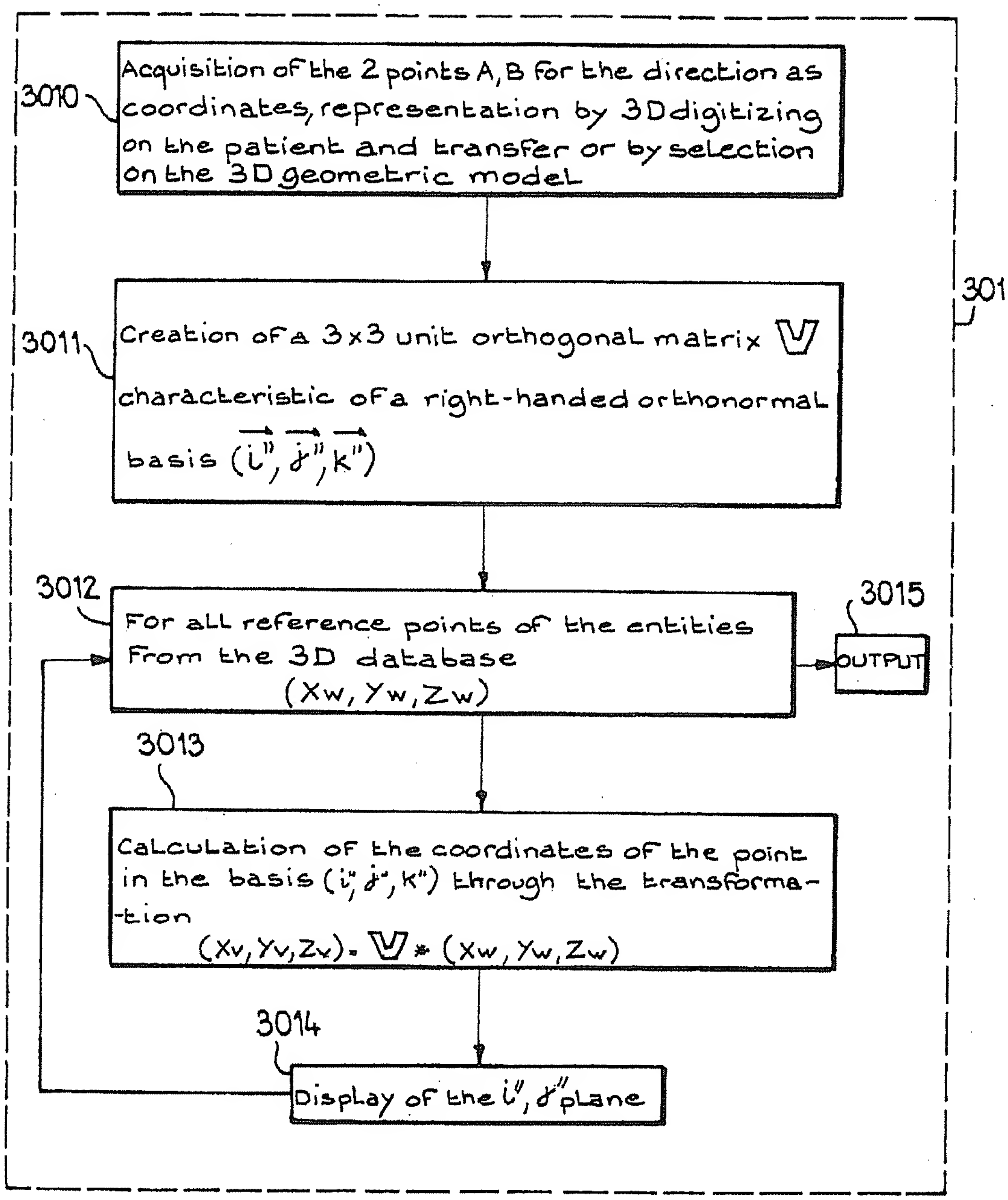
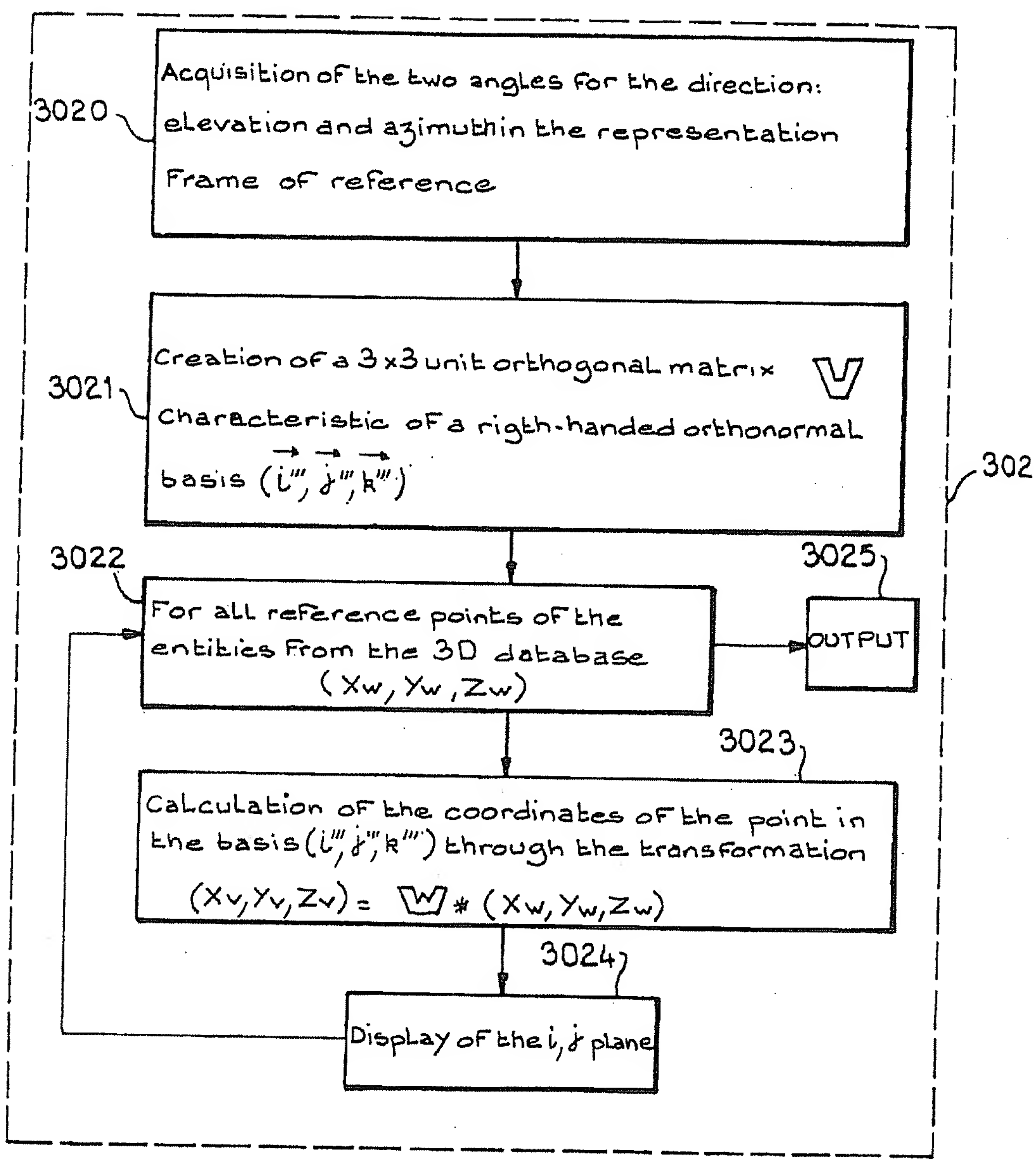

Acquisition of the 2 points A, B for the direction as coordinates, representation by 3D digitizing on the patient and transfer or by selection on the 3D geometric model
3010
Creation of a 3x3 unit orthogonal matrix V characteristic of a right-handed orthonormal basis (i", j", k")
3011
301
3012
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3015
OUTPUT
3013
Calculation of the coordinates of the point in the basis (i", j", k") through the transformation (Xv, Yv, Zv) = V * (Xw, Yw, Zw)
3014
Display of the i", j" plane

FIG_9a



3020
Acquisition of the two angles for the direction: elevation and azimuth in the representation frame of reference
3021
Creation of a 3x3 unit orthogonal matrix V characteristic of a rigth-handed orthonormal basis (i''', j''', k''')
302
3022
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3025
OUTPUT
3023
Calculation of the coordinates of the point in the basis (i''', j''', k''') through the transformation (Xv, Yv, Zv) = W * (Xw, Yw, Zw)
3024
Display of the i, j plane

FIG_9b

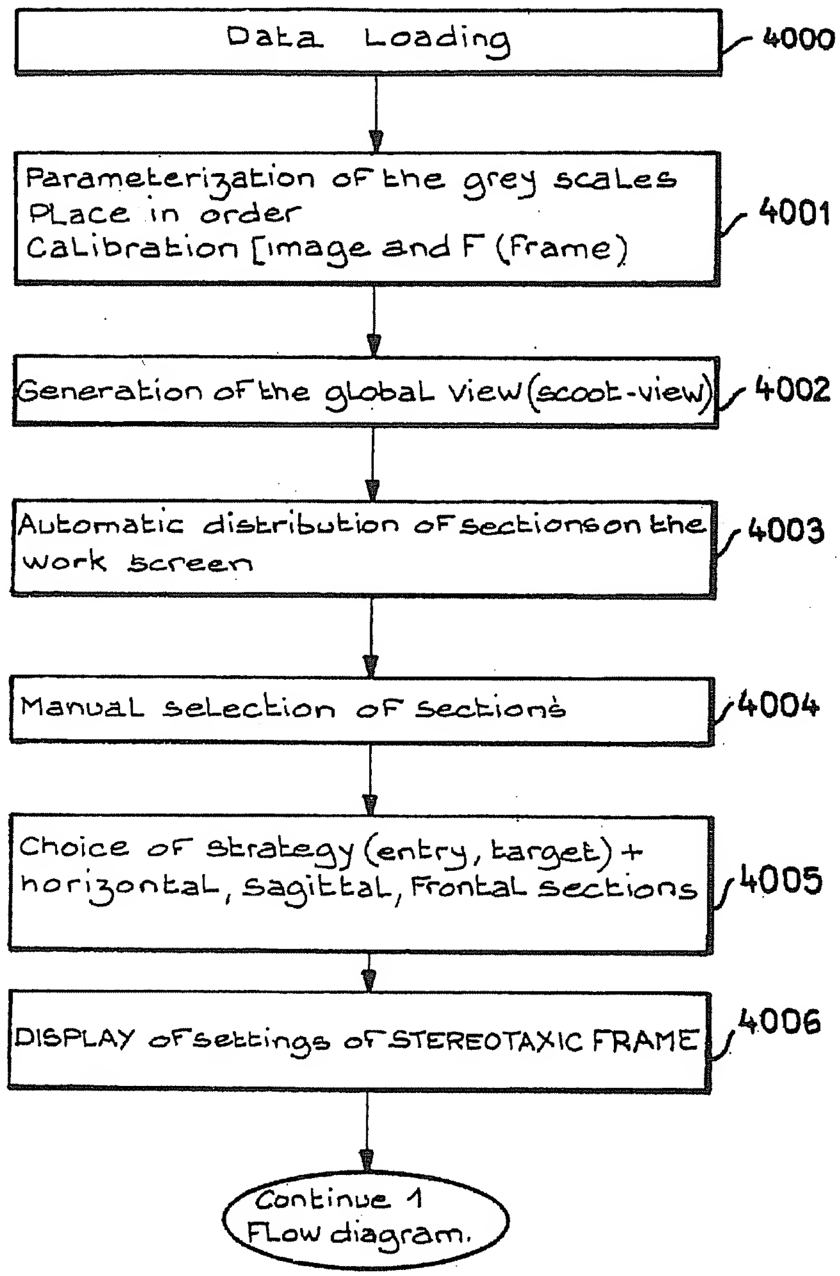

Data Loading
4000
Parameterization of the grey scales
Place in order
Calibration [image and F (frame)
4001
Generation of the global view (scoot-view)
4002
Automatic distribution of sections on the work screen
4003
Manual selection of sections
4004
Choice of strategy (entry, target) + horizontal, sagittal, frontal sections
4005
DISPLAY of settings of STEREOTAXIC FRAME
4006
Continue 1
Flow diagram.

FIG_10a

FIG_10b

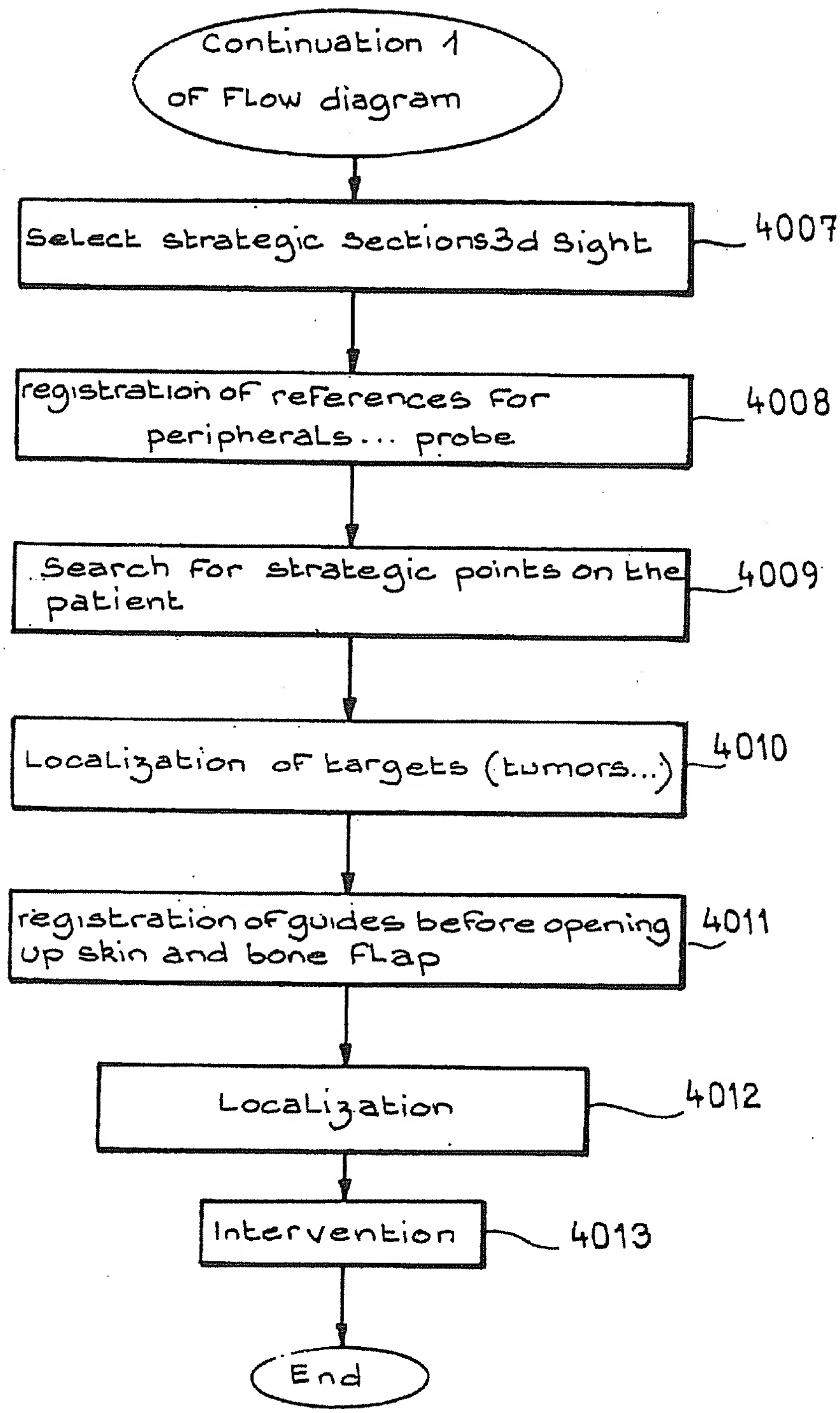
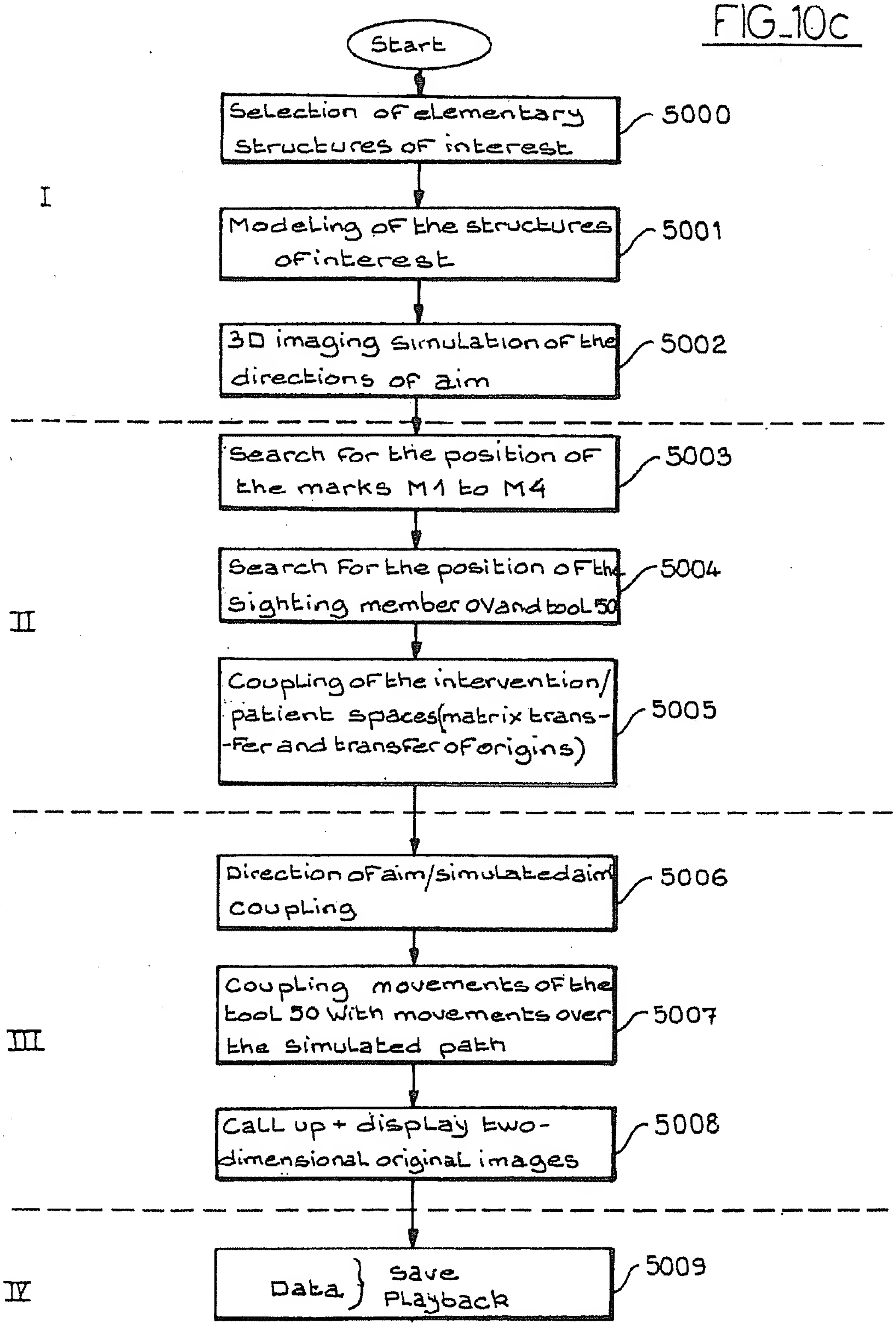

Continuation 1 of Flow diagram
Select strategic sections3d sight
4007
registration of references for peripherals... probe
4008
Search for strategic points on the patient
4009
Localization of targets (tumors...)
4010
registration of guides before opening up skin and bone flap
4011
Localization
4012
Intervention
4013
End

FIG_10c


Start
Selection of elementary structures of interest
5000
I
Modeling of the structures of interest
5001
3D imaging simulation of the directions of aim
5002
Search for the position of the marks M1 to M4
5003
Search for the position of the sighting member OV and tool 50
5004
II
Coupling of the intervention/patient spaces (matrix trans-fer and transfer of origins)
5005
Direction of aim/simulated aim coupling
5006
Coupling movements of the tool 50 with movements over the simulated path
5007
III
Call up + display two-dimensional original images
5008
Data
Save
Playback
5009
IV

INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE

The invention relates to an interactive system for local intervention inside a region of a nonhomogeneous structure.

The performing of local interventions inside a nonhomogeneous structure, such as intracranial surgical operations or orthopedic surgery currently poses the problem of optimizing the intervention path or paths so as to secure, on the one hand, total intervention over the region or structure of interest, such as a tumor to be treated or explored and, on the other hand, minimal lesion to the regions neighboring or adjoining the region of interest, this entailing the localizing and then the selecting of the regions of the nonhomogeneous structure which are least sensitive to being traversed or the least susceptible to damage as regards the integrity of the structure.

Numerous works aimed at providing a solution to the abovementioned problem have hitherto been the subject of publications. Among the latter may be cited the article entitled "Three Dimensional Digitizer (Neuronavigator): New Equipment for computed Tomography Guided Stereotaxic Surgery", published by Eiju Watanabe, M.D., Takashi Watanabe, M.D., Shinya Manaka, M.D., Yoshiaki Mayanagi, M.D., and Kintomo Takakura, M.D. Department of Neurosurgery, Faculty of Medicine, University of Tokyo, Japan, in the journal Surgery Neurol. 1987: 27 pp. 543–547, by Elsevier Science Publishing Co., Inc. The Patent WO-A-88 09151 teaches a similar item of equipment.

In the abovementioned publications are described in particular a system and an operational mode on the basis of which a three-dimensional position marking system, of the probe type, makes it possible to mark the three-dimensional position coordinates of a nonhomogeneous structure, such as the head of a patient having to undergo a neurosurgical intervention, and then to put into correspondence as a function of the relative position of the nonhomoc.eneous structure a series of corresponding images consisting of two-dimensional images sectioned along an arbitrary direction, and obtained previously with the aid of a medical imaging method of the "scanner" type.

The system and the operational mode mentioned above offer a sure advantage for the intervening surgeon since the latter has available, during the intervention, apart from a direct view of the intervention, at least one two-dimensional sectional view enabling him to be aware, in the sectional plane, of the state of performance of the intervention.

However, and by virtue of the very design of the system and of the operational mode mentioned above, the latter allow neither a precise representation of the state of performance of the intervention, nor partially or totally automated conduct of the intervention in accordance with a program for advance of the instrument determined prior to the intervention.

Such a system and such an operational mode cannot therefore claim to eradicate all man-made risk, since the intervention is still conducted by the surgeon alone.

The objective of the present invention is to remedy the whole of the problem cited earlier, and in particular to propose a system permitting as exact as possible a correlation, at any instant, between an intervention modeling on the screen and the actual intervention, and furthermore the representation from one or more viewing angles, and if appropriate in one or more sectional planes, of the nonhomogeneous structure, the sectional plane or planes possibly being for example perpendicular to the direction of the path of advance of the instrument or of the intervention tool.

Another objective of the present invention is also the implementation of a system permitting simulation of an optimal trajectory of advance of the tool, so as to constitute an assisted or fully programed intervention.

Finally, an objective of the present invention is to propose a system making it possible, on the basis of the simulated trajectory and of the programed intervention, to steer the movement of the instrument or tool to the said trajectory so as to carry out the programed intervention.

The invention proposes to this effect an interactive system for local intervention inside a region of a nonhomogeneous structure to which is tied a reference structure containing a plurality of base points, characterized in that it comprises:

- means of dynamic display by three-dimensional imaging of a representation of the nonhomogeneous structure and of a reference structure tied to the nonhomogeneous structure, including images of the base points,
- means of delivering the coordinates of the images of the base points in the first reference frame,
- means of securing the position of the non-homogeneous structure and the reference structure with respect to a second reference frame,
- marker means for delivering the coordinates of the base points in the second reference frame,
- means of intervention comprising an active member whose position is determined with respect to the second reference frame,
- means of optimizing the transfer of reference frames from the first reference frame to the second reference frame and vice versa, on the basis of the coordinates of the images of the base points in the first reference frame and of the coordinates of the base points in the second reference frame, in such a way as to reduce to a minimum the deviations between the coordinates of the images of the base points in the first reference frame and the coordinates of the base points, expressed in the said first reference frame with the aid of the said reference frame transfer tools,
- means for defining with respect to the first reference frame a simulated origin of intervention and a simulated direction of intervention, and
- reference frame transfer means using the said reference frame transfer tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

A more detailed description of the system of the invention will be given below with reference to the drawings in which:

FIG. **1** represents a general view of an interactive system for local intervention inside a region of a nonhomogeneous structure according to the present invention,

FIG. **2** represents, in the case where the nonhomogeneous Structure consists of the head of a patient, and with a view to a neurosurgical intervention, a reference structure tied to the nonhomogeneous structure and enabling a correlation to be established between a "patient" reference frame and a reference frame of images of the patient which were made and stored previously,

FIG. **3** represents an advantageous embodiment of the spacial distribution of the reference structure of FIG. **2**,

FIG. **4** preesents an advantageous embodiment of the intervention means set up on an operating table in the case of a neurosirgical intervention,

FIGS. *5a* and *5b* represent a general flow diagram of functional steps implemented by the system,

FIGS. **6** thru **8** represent flow diagrams of programs permitting implementation of certain functional steps of FIG. **5***b*,

FIG. **9***a* represents a flow diagram of a program permitting implementation of a functional step of FIG. **5***a*,

FIG. **9***b* represents a flow diagram of a program permitting implementation of another functional step of FIG. **5***a*,

FIGS. **10***a* and **10***b* represent a general flow diagram of the successive steps of an interactive dialogue between the system of the present invention and the intervening surgeon and

FIG. **10***c* represents a general flow diagram of the successive functional steps carried out by the system of the invention, having (sic) the intervention, prior to the intervention, during the intervention and after the intervention.

The interactive system for local intervention according to the invention will firstly be described in connection with FIG. **1**.

A nonhomogeneous structure, denoted SNH, on which an intervention is to be performed, consists for example of the head of a patient in which a neurosurgical intervention is to be performed. It is however understood that the system of the invention can be used to carry out any type of intervention in any type of nonhomogeneous structure inside which structural and/or functional elements or units may be in evidence and whose integrity, during the intervention, is to be respected as far as possible.

The system comprises means, denoted **1**, of dynamic display by three-dimensional imaging, with respect to a first reference frame R_1, of a representation (denoted RSR) of a reference structure SR (described later) tied to the structure SNH, and a representation or modeling of the nonhomogeneous structure, denoted RSNH.

More precisely, the means **1** make it possible to display a plurality of successive three-dimensional images, from different angles, of the representations RSNH and RSR.

The system of the invention also comprises means, denoted **2**, of tied positioning, with respect to a second reference frame R_2, of the structures SNH and SR.

In the present non-limiting example, the head of the patient, bearing the reference structure SR, is fixed on an operating table TO to which are fixed the means **2** of tied positioning.

Of course, the patient whose head has been placed in the means **2** for tied positioning has previously been subjected to the customary preparations, in order to enable him to undergo the intervention.

The means **2** of the tied positioning with respect to R_2 will not be described in detail since they can consist of any means (such as a retaining headset) normally used in the field of surgery or neurosurgery. The reference frame R_2 can arbitrarily be defined as a tri-rectangular reference trihedron tied to the operating table TO, as represented in FIG. **1**.

Means **3** of marking, with respect to the second reference frame R_2, the coordinates, denoted X2, Y2, Z2, of arbitrary points, and in particular of a certain number of base points of the reference structure SR are furthermore provided.

These base points constituting the reference structure SR can consist of certain notable points and/or of marks fixed to the patient, at positions selected by the surgeon and in particular at these notable points.

The system of the invention further comprises computing means **4** receiving means **3** of marking the coordinates X2, X2, Z2.

The computing means **4**, as will be seen in detail later, are designed to elaborate optimal tools for reference frame transfer using on the one hand the coordinates in R_2, measured by the probe **3**, of a plurality of base points of the structure SR, and on the other hand the coordinates in R_1, determined by graphical tools of the computer **M01** (pointing by mouse, etc.), of the images of the corresponding base points in the representation RSR, so as to secure the best possible correlation between the information modeled in the computer equipment and the corresponding real-world information.

There is furthermore provision for reference frame transfer means **11** designed to use the tools thus elaborated and to secure this correlation in real time.

Moreover, means **40** are provided, as will be seen in detail later, for determining or modeling a reference origin of intervention ORI and a direction of intervention Δ.

With the aid of the means **11**, the modeled direction of intervention Δ can, at least prior to the intervention and at the start of the intervention, be materialized through an optical sighting system available to the surgeon, it being possible to steer this sighting system positionally with respect to the second reference frame R_2.

The sighting system will be described later.

The system of the present invention finally comprises means **5** of intervention comprising an active member, denoted **50**, whose position is specified with respect to the second reference frame R_2. The active member can consist of the various tools used in surgical intervention. For example, in the case of an intercranial neurosurgical intervention, the active member could be a trephining tool, a needle, a laser or radioscope emission head, or an endoscopic viewing system.

According to an advantageous characteristic of the invention, by virtue of the reference frame transfer means **11**, the position of the active member can be controlled dynamically on the basis of the prior modeling of the origin of intervention ORI and of the direction of intervention Δ.

The means **1** of dynamic display by three-dimensional imaging of the representations RSNH and RSR comprise a file **10** of two-dimensional image data. The file **10** consists for example of digitized data from tomographic sections, from radiographs, from maps of the patient's head, and contained in an appropriate mass memory.

The successive tomographic sections can be produced prior to the intervention in a conventional manner, after the reference structure SR has been put in place on the nonhomogeneous structure SNH.

According to an advantageous feature, the reference structure SR can consist of a plurality of marks or notable points which can be both sensed by the marker means **3** and detected on the two-dimensional images obtained.

Of course, the abovementioned two-dimensional tomographic sections can likewise be produced by any medical imaging means such as a nuclear magnetic resonance system.

In a characteristic and well-known manner, each two-dimensional image corresponding to a tomographic scanner section corresponds to a structural slice thickness of about 2 to 3 mm, the pixels or image elements in the plane of the tomographic section being obtained with a precision of the order of ±1 mm. It is therefore understood that the marks or points constituting the reference structure SR appear on the images with a positional uncertainty, and an important feature of the invention will consist in minimizing these uncertainties as will be described later.

The system also comprises first means **110** for calculating and reconstructing three-dimensional images from the data from the file **10**.

It also comprises a high-resolution screen **12** permitting the displaying of one or more three-dimensional or two-dimensional images constituting so many representations of the reference structure RSR and of the nonhomogeneous structure SNH.

Advantageously, the calculating means **110**, the high-resolution screen and the mass memory containing the file **10** form part of a computer of the workstation type with conventional design and denoted MO1.

Preferably, the first calculating means **110** can consist of a CAD type program installed in the workstation MO1.

By way of non-limiting example, this program can be derived from the software marketed under the tradename "AUTOCAD" by the "AUTODESK" company in the United States of America.

Such software makes it possible, from the various digitized two-dimensional images, to reconstruct threedimensional images constituting the representations of the structures RSR and RSNH in arbitrary orientations.

Thus, as has furthermore been represented in FIG. **1**, the calculating means **4** and **11** can consist of a third computer, denoted MO2 in FIG. **1**.

The first and second computers MO1 and MO2 are interconnected by a conventional digital link (bus or network).

As a variant, the computers MO1 and MO2 can be replaced by a single workstation.

The marker means **3** consist of a three-dimensional probe equipped with a tactile tip **30**.

This type of three-dimensional probe, known per se and not described in detail, consists of a plurality of hinged arms, marked in terms of position with respect to a base integral with the operating table TO. It makes it possible to ascertain the coordinates of the tactile tip **30** with respect to the origin O_2 of the reference frame R_2 with a precision better than 1 mm.

The probe is for example equipped with resolvers delivering signals representing the instantaneous position of the abovementioned tactile tip **30**. The resolvers are themselves connected to the circuits for digital/analog conversion and sampling of the values representing these signals, these sampling circuits being interconnected in conventional manner to the second computer MO2 in order to supply it with the coordinates X2, X2, Z2 of the tactile tip **30**.

As a variant or additionally, and as represented diagrammatically, the marker means **3** can comprise a set of video cameras **31** and **32** (or else infrared cameras) enabling pictures to be taken of the structures SNH and SR.

The set of cameras can act as a stereoscopic system permitting the positional plotting of the base points of the reference structure SR, or of other points of the nonhomogeneous structure SNH, with respect to the second reference frame R_2. The positional plotting can be done for example by appending a laser beam emission system making it possible to illuminate successively the points whose coordinates are sought, appropriate software making it possible to then determine the position of these points one by one with respect to R_2. This software will not be described since it can consist of position and shape recognition software normally available on the market.

According to another variant, the marker means **3** can comprise a telemetry system.

In this case, the marks of the structure SR can consist of small radiotransmitters implanted for example on the relevant points of the patient's head and designed to be visible on the two-dimensional images, appropriate electromagnetic or optical sensors (not shown) being provided in order to determine the coordinates of the said marks in the reference frame R_2 or in a reference frame tied to the latter.

It is important to note here that the general function of the base points of the reference structure is, on the one hand, to be individually localizable on the reference structure, in order to deduce from this the coordinates in R_2, and on the other hand, to be visualizable on the two-dimensional images so as to be identified (by their coordinates in R_1) and included in the representation RSR on the screen.

It can therefore involve special marks affixed at arbitrary points of the lateral surface of the structure SNH, or else at notable points of the latter, or else, when the notable points can in themselves be localized with high precision both on the structure SNH and on the **2**D sections, notable points totally devoid of marks.

In FIG. **2** a plurality of marks, denoted **M1** to **Mi**, these marks, in the case where the nonhomogeneous structure consists of the head of a patient, being localized for example between the eyebrows of the patient, on the latter's temples, and at the apex of the skull at a notable point such as the frontal median point.

More generally, for a substantially ovoid volume constituting the nonhomogeneous structure, there is advantageously provision for four base points at least on the outer surface of the volume.

Thus, as has been represented in FIG. **3**, the four marks M1 to M4 of the reference structure are distributed so as preferably to define a more or less symmetric tetrahedron. The symmetry of the tetrahedron, represented in FIG. **3**, is materialized by the vertical symmetry plane PV and the horizontal symmetry plane PH.

According to an advantageous characteristic, as will be seen later, the means of elaborating the reference frame transfer tools are designed to select three points of the tetrahedron which will define the "best plane" for the reference frame transfer.

Also, the presence of four or more points enables the additional point(s) to validate a specified selection.

More precisely, the presence of a minimum of four base points on the reference structure makes it possible to search for the minimum distortion between the points captured on the patient by the marker means consisting for example of the three-dimensional probe and the images of these points on the representation by three-dimensional imaging, the coordinates of which are calculated during processing. The best plane of the tetrahedron described earlier, that is to say the plane for which the uncertainty in the coordinates of the points between the points actually captured by the three-dimensional probe and the points of the representation of the reference structure RSR, is minimal, then becomes the reference plane for the reference frame transfer. Thus, the best correlation will be established between a modeled direction of intervention and a modeled origin of intervention, on the one hand, and the action of the member **50**. Preferably, the origin of intervention will be placed at the center of the region in which the intervention is to be carried out, that is to say a tumor observed or treated for example.

Furthermore, it will be possible to take the noted residual uncertainty into account in order to effect the representation of the model and of the tools on the dynamic display means.

A more detailed description of the means of intervention **5** will now be given in connection with FIG. **4**.

Preferably, the means of intervention **5** comprise a carriage **52** which is translationally mobile along the operating table TO, for example on a rack, denoted **54**, whilst being driven by a motor, not shown, itself controlled by the computer MO2 for example, via an appropriate link. This

movement system will not be described in detail since it corresponds to a conventional movement system available on the market. As a variant, the carriage **52** can be mobile over a distinct path separated from the operating table TO, or immobile with respect to the operating table and then constitute a support.

The support carriage **52** comprises in the first place a sighting member OV, constituting the above-mentioned sighting system, which can consist of a binocular telescope.

The sighting member OV enables the surgeon, prior to the actual intervention, or during the latter, to sight the presumed position of the region in which the intervention is to be carried out.

Furthermore, and in a non-limiting manner, with the sighting member OV can be associated a helium-neon laser emission system, denoted EL, making it possible to secure the aiming of a fine positioning or sighting laser beam on the structure SNH and in particular, as will be seen in detail later, to indicate to the surgeon the position of an entry point PE prior to the intervention, to enable the latter to open the skull at the appropriate location, and likewise to indicate to him what the direction of intervention will be. Additionally, the illuminating of the relevant point of the nonhomogeneous structure or at the very least the lateral surface of the latter enables the video cameras **31** and **32** to carry out, if necessary, a positional plotting.

Preferably, a system for measuring position by telemetry **53** is provided to secure the precise measurement of the position of the support carriage **52** of the sighting member OV and of the laser emission system EL. During the operation, and in order to secure the intervention, the carriage **52** can be moved along the rack **54**, the position of the carriage **52** being measured very precisely by means of the system **53**. The telemetry system **53** is interconnected with the microcomputer MO2 by an appropriate link.

The means of intervention **5** can advantageously consist of a guide arm **51** for the active member **50**.

The guide arm **51** can advantageously consist of several hinged segments, each hinge being equipped with motors and resolvers making it possible to secure control of movement of the end of the support arm and the positional plotting of this same end and therefore of the active member **50** according to six degrees of freedom with respect to the carriage **52**. The six degrees of freedom comprise, of course, three translational degrees of freedom with respect to a reference frame tied to the carriage **52** and three rotational degrees of freedom along these same axes.

Thus, the support arm **51** and the member **50** are marked in terms of instantaneous position with respect to the second reference frame R_2, on the one hand by way of the positional plot of the mobile carriage **52** and, on the other hand, by way of the resolvers associated with each hinge of the support arm **51**.

In the case of an intracranial neurosurgical surgical intervention, the active member **50** can be removed and can consist of a trephining tool, a needle or radioactive or chemical implant, a laser or radioisotope emission head or an endoscopic viewing system. These various members will not be described since they correspond to instruments normally used in neurosurgery.

The materializing of the modeled direction of intervention can be effective by means of the laser emitter EL. This sighting being performed, the guide arm **51** can then be brought manually or in steered manner into superposition with the direction of intervention Δ.

In the case of manual positioning, the resolvers associated with the sighting member OV and the laser emitter EL, if appropriate, make it possible to record the path of the sighting direction, constituting in particular the actual direction of intervention, on the representation of the nonhomogeneous structure in the dynamic display means **1**.

Furthermore, as will be described later and in preferential manner, the intervening surgeon will be able firstly to define a simulated intervention path and steer thereto the movements of the active member **50** in the nonhomogeneous structure in order effectively to secure all or part of the intervention.

In this case, the progress of the intervention tool **50** is then steered directly to the simulated path (data ORI, Δ) by involving the reference frame transfer means **11** in order to express the path in the reference frame R_2.

A more detailed description of the implementation of the operational mode of the system of the invention will now be described in connection with FIGS. *5a* and *5b*.

According to FIG. *5a*, the first step consists in obtaining and organizing in memory the two-dimensional image data (step **100**). Firstly, the nonhomogeneous structure SNH is prepared. In the case of a neurosurgical intervention for example, this means that the patient's head can be equipped with marks constituting the base points of the reference structure SR. These marks can be produced by means of points consisting of a dye partially absorbing the X-rays, such as a radiopaque dye.

The abovementioned marks are implanted by the surgeon on the patient's head at notable points of the latter [sic], and images can then be taken of the nonhomogeneous structure SNH by tomography for example, by means of an apparatus of the X-ray scanner type.

This operation will not be described in detail since it corresponds to conventional operations in the field of medical imaging.

The two-dimensional image data obtained are then constituted as digitized data in the file **10**, these data being themselves marked with respect to the reference frame R_1 and making it possible, on demand, to restore the two-dimensional images onto the dynamic display means **1**, these images representing superimposed sections of the nonhomogeneous structure SNH.

From the digitized image data available to the surgeon, the latter then proceeds, as indicated at **101** in FIG. *5a*, to select the structures of interest of the abovementioned images.

The purpose of this step is to facilitate the work of the surgeon by forming three-dimensional images which contain only the contours of the elements of the structure which are essential for geometrical definition and real-time monitoring of the progress of the intervention.

In the case where the nonhomogeneous structure SNH consists of the head of a patient, an analysis of the two-dimensional image data makes it possible, from values of optical density of the corresponding image-points, straightaway to extract the contours of the skull, to check the distance scales, etc.

Preferably, the abovementioned operations are performed on a rectangle of interest for a given two-dimensional image, this making it possible, by moving the rectangle of interest, to cover the whole of the image.

The above analysis is performed by means of suitable software which thus makes it possible to extract and vectorize the contours of the structures which will be modeled in the representations RSNH and RSR.

The structures modeled in the case of a neurosurgical intervention are for example the skull, the cerebral ventricles, the tumor to be observed or treated, the falx cerebri, and the various functional regions.

According to a feature of the interactive system of the invention, the surgeon may have available a digitizing table or other graphics peripheral making it possible, for each displayed two-dimensional image, to rectify or complete the definition of the contour of a particular region of interest.

It will be noted finally that by superimposing the extracted contours on the displayed two-dimensional image, the surgeon will be able to validate the extractions carried out.

The extracted contours are next processed by sampling points to obtain their coordinates in the reference frame R_1, it being possible to constitute these coordinates as an ASCII type file. This involves step **102** for generating the three-dimensional data base.

This step is followed by a step **103** of reconstructing the three-dimensional model. This step consists firstly, with the aid of the CAD type software, in carrying out on the basis of the contours of the structures of interest constituted as vectorized two-dimensional images an extrapolation between the various sectional planes.

The abovementioned extrapolation is carried out preferably by means of a "B-spline" type algorithm which seems best suited. This extrapolation transforms a discrete item of information, namely the successive sections obtained by means of the scanner analysis, into a continuous model permitting three-dimensional representation of the volume envelopes of the structures.

It should be noted that the reconstruction of the volumes constituting the structures of interest introduces an approximation related in particular to the spacing and non-zero thickness of the acquisition sections. An important characteristic of the invention, as explained in detail elsewhere, is on the one hand to minimize the resulting uncertainties in the patient-model correlation, and on the other hand to take into account the residual uncertainties.

The CAD type software used possesses standard functions which enable the model to be manipulated in space by displaying it from different viewpoints through just a criterion defined by the surgeon (step **104**).

The software can also reconstruct sectional representation planes of the nonhomogeneous structure which differ from the planes of the images from the file **10**, this making it possible in particular to develop knowledge enhancing the data for the representation by building up a neuroanatomical map.

The surgeon can next (step **105**) determine a model of intervention strategy taking into account the modeled structures of interest, by evaluating the distance and angle ratios on the two-and three-dimensional representations displayed.

This intervention strategy will consist, in actual fact, on the one hand in localizing the tumor and in associating therewith a "target point", which will subsequently be able to substitute for the origin common to all the objects (real and images) treated by the system, and on the other hand in determining a simulated intervention path respecting to the maximum the integrity of the structures of interest. This step can be carried out "in the office", involving only the workstation.

Once this operation is performed and prior to the intervention, the following phase consists in implementing the steps required to establish as exact as possible a correlation between the structure SNH (real world) and the representation RSNH (computer world). This involves steps **106** to **109** of FIG. *5b*.

Firstly, as represented in FIG. *5b* at step **107**, marking of the base points of the reference structure SR with respect to the second reference frame is carried out with the aid of the marker means **3**, by delivering to the system the coordinates **X2**, **Y2**, **Z2** of the said base points.

The following step **106** consists in identifying on the representations RSNH and RSR displayed on the screen the images of the base points which have just been marked. More precisely, with the aid of appropriate graphics peripherals, these representations (images) of the base points are selected one by one, the workstation supplying on each occasion (in this instance to the computer MO2) the coordinates of these points represented in the reference frame R_1.

Thus the computer MO2 has available a first set of three-dimensional coordinates representing the position of the base points in R_2, and a second set of three-dimensional coordinates representing the position of the representations of the base points in R_1.

According to an essential feature of the invention, these data will be used to elaborate at **108**, **109**, tools for reference frame transfer (from R_1 to R_2 and vice versa) by calling upon an intermediate reference frame determined from the base points and constituting an intermediate reference frame specific to the reconstructed model.

More precisely, the intermediate reference frame is constructed from three base points selected so that, in this reference frame, the coordinates of the other base points after transfer from R_2 and the coordinates of the representations of these other base points after transfer from R_1 are expressed with the greatest consistency and minimum distortion.

When the step of elaborating the reference frame transfer tools is concluded, these tools can be used by he system to secure optimal coupling between the real world and the computer world (step **1110**).

Furthermore, according to a subsidiary feature of the present invention, the system can create on the display means a representation of the nonhomogeneous structure and of the intervention member which takes account of the deviations and distortions remaining after the "best" reference frame transfer tools have been selected (residual uncertainties). More precisely, from these deviations can be deduced by the calculating means a standard error likely to appear in the mutual positioning between the representation of the nonhomogeneous structure and the representation of elements (tools, sighting axes, etc.) referenced on R_2 when using the reference frame transfer tools. This residual uncertainty, which may in practice be given substance through an error matrix, can be used for example to represent certain contours (tool, structures of interest to be avoided during the intervention, etc.) with dimensions larger than those which would normally be represented starting from the three-dimensional data base or with the aid of coordinates marked in R_2, the said larger dimensions being deduced from the "normal" dimensions by involving the error matrix. For example, if the member were represented normally, in transverse section, by a circle of diameter D1, a circle of diameter D2>D1 can be represented in substance, with the difference D2-D1 deduced from the standard error value. In this way, when a direction of intervention will be selected making it possible to avoid traversing certain structures of interest, the taking into account of an "enlarged" size of the intervention tool will eradicate any risk of the member, because of the abovementioned errors, accidently traversing these structures.

Back at step **105**, and as will be seen in more detail with reference to FIGS. *9a* and *9b*, the reference origin of intervention ORI and the direction of intervention Δ, that is to say the simulated intervention path, can be determined according to various procedures.

According to a first procedure, the trajectory can be defined from two points, namely an entry point PE (FIG. **3**)

and a target point, that is to say substantially the center of the structure of interest consisting of the tumor to be observed or treated. Initially, these two points are localized on the model represented on the screen.

According to a second methodology, the trajectory can be determined from the abovementioned target point and from a direction which takes account of the types of structures of interest and of their positions with a view to optimally respecting their integrity.

After the abovementioned step **108**, the surgeon can at step **1110** perform the actual intervention.

The intervention can advantageously be performed by steering the tool or active member over the simulated intervention path, determined in step **1110**.

As a variant, given that the support arm **51** for the active member, equipped with its resolvers, continuously delivers the coordinates in R_2 of the said active member to the system, it is also possible to perform the operation manually or semi-manually, by monitoring on the screen the position and motions of a representation of the tool and by comparing them with the simulated, displayed intervention path.

It will furthermore be noted that the modeled direction of intervention can be materialized with the aid of the laser beam described earlier, the positioning of the latter (with respect to R_2) being likewise carried out by virtue of the reference frame transfer tools.

Certain functional features of the system of the invention will now be described in further detail with reference to FIGS. **6**, **7**, **8**, **9***a* and **9***b*.

The module for elaborating the reference frame transfer tools (steps **108**, **109** of FIG. **5***b*) will firstly be described with reference to FIG. **6**.

This module comprises a first sub-module **1001** for acquiring three points A, B, C, the images of the base points of SR on the representation RSNH (the coordinates of these points being expressed in the computer reference frame R_1), by successive selections of these points on the representation. To this effect, the surgeon is led, by means of a graphics interface such as a "mouse" to point successively at the three selected points A, B, C.

The module for preparing the transfer tools also comprises a second sub-module, denoted **1002**, for creating a unit three-dimensional orthogonal matrix M, this matrix being characteristic of a right-handed orthonormal basis represented by three unit vectors $\vec{i}$, $\vec{j}$, $\vec{k}$, which define an intermediate reference frame tied to R_1.

The unit vectors $\vec{i}$, $\vec{j}$ and $\vec{k}$ are given by the relations:

$$\vec{j}=\overrightarrow{AB}/\|\overrightarrow{AB}\|$$

$$\vec{k}=\left(\overrightarrow{BA}\wedge\overrightarrow{BC}\right)/\|\overrightarrow{BA}\wedge\overrightarrow{BC}\|$$

$$\vec{i}=\vec{j}\wedge\vec{k}$$

where $\| \|$ designates the norm of the relevant vector.

In the above relations, the sign "$\wedge$" designates the vector product of the relevant vectors.

Similarly, the module for preparing the transfer tools comprises a third sub-module, denoted **1003**, for acquiring three base points D, E, F, of the structure SR, these three points being those whose images on the model are the points A, B, C respectively. For this purpose, the surgeon, for example by means of the tactile tip **30**, successively senses these three points to obtain their coordinates in R_2.

The sub-module **1003** is itself followed, as represented in FIG. **6**, by a fourth sub-module **1004** for creating a unit three-dimensional orthogonal matrix N, characteristic of a right-handed orthonormal basis comprising three unit vectors $\vec{i}'$, $\vec{j}'$ $\vec{k}'$ and which is tied to the second reference frame R_2 owing to the fact that the nonhomogeneous structure SNH is positionally tied with respect to this reference frame.

The three unit vectors $\vec{i}'$, $\vec{j}'$, $\vec{k}'$ are defined by the relations:

$$\vec{j}'=\overrightarrow{DE}/\|\overrightarrow{DE}\|$$

$$\vec{k}'=\left(\overrightarrow{ED}\wedge\overrightarrow{EF}\right)/\|\overrightarrow{ED}\wedge\overrightarrow{EF}\|$$

$$\vec{i}'=\vec{j}'\wedge\vec{k}'$$

As indicated above, to the extent that the base points of the reference structure can be marked in R_2 with high precision, so their representation in the computer base R_1 is marked with a certain margin of error given on the one hand the non-zero thickness (typically from 2 to 3 mm) of the slices represented by the two-dimensional images from the file **10**, and on the other hand (in general to a lesser extent) the definition of each image element or pixel of a section.

According to the invention, once a pair of transfer matrices M, N has been elaborated with selected points A, B, C, D, E, F, it is sought to validate this selection by using one or more additional base points; more precisely, for the or each additional base point, this point is marked in R_2 with the aid of the probe **30**, the representation of this point is marked in R_1 after selection on the screen, and then the matrices N and M are applied respectively to the coordinates obtained, in order to obtain their expressions in the bases ($\vec{i}'$, $\vec{j}'$, $\vec{k}'$) and ($\vec{i}$, $\vec{j}$, $\vec{k}$) respectively. If these expressions are in good agreement, these two bases can be regarded as a single intermediate reference frame, this securing the exact as possible mathematical coupling between the computer reference frame R_1 tied to the model and the "real" reference frame R_2 tied to the patient.

In practice, the module for elaborating the reference frame transfer tools can be designed to perform steps **1001** to **1004** in succession on basic triples which differ on each occasion (for example, if four base points have been defined associated with four representations in RSR, there are four possible triples), in order to perform the validation step **1005** for each of these selections and finally in order to choose the triple for which the best validation is obtained, that is to say for which the deviation between the abovementioned expressions is smallest. This triple defines the "best plane" mentioned elsewhere in the description, and results in the "best" transfer matrices M and N.

As a variant, it will be possible for the selection of the best plane to be made at least in part by the surgeon by virtue of his experience.

It should be noted that the reference frame transfer will only be concluded by supplementing the matrix calculation with the matrices M, N with a transfer of origin, so as to create a new common origin for example at the center of the tumor to be observed or treated (point ORI). This transfer of origin is effected simply by appropriate subtraction of vectors on the one hand on the coordinates in R_1, and on the other hand on the coordinates in R_2. These vectors to be subtracted are determined after localization of the center of the tumor on the representation.

Furthermore, the means described above for establishing the coupling between the patient's world and the model's world can also be used to couple to the model's world that of map data, also stored in the workstation and expressed in a different reference frame denoted R_3. In this case, since these data contain no specific visible mark, the earlier described elaboration of matrices is performed by substituting for these marks the positions of notable points of the patient's head. These may be temporal points, the frontal median point, the apex of the skull, the center of gravity of the orbits of the eyes, etc.

The corresponding points of the model can be obtained either by selection by mouse or graphics tablet on the model, or by sensing on the patient himself and then using the transfer matrices.

The above step of elaborating the reference frame transfer tools, conducted in practice by the calculating means **4**, makes it possible subsequently to implement the reference frame transfer means (FIGS. **7** and **8**).

With reference to FIG. **7**, the first transfer sub-module **201** comprises a procedure denoted **2010** for aquiring the coordinates XM, YM, ZM, expressed in R_1, of the point to be transferred, by selecting on the representation.

The procedure **2010** followed by a procedure **2011** for calculating the coordinates XP, YP, ZP (expressed in R_2) of the corresponding real point on the patient through the transformation:

{XP, YP, ZP}=M*N^{-1}*{XM, YM, ZM} where M * N^{-1} represents the product of the matrix M and the inverse matrix N.

The procedure **2011** is followed by a processing procedure **2012** utilizing the calculated coordinates XP, YP, ZP, for example to indicate the corresponding point on the surface of the structure SNH by means of the laser emission system EL, or again to secure the intervention at the relevant point with coordinates XP, YP, ZP (by steering the active member).

Conversely, in order to secure a transfer from SNH to RSNH, the second sub-module **202** comprises (FIG. **8**) a procedure denoted **2020** for acquiring on the structure SNH the coordinates XP, YP, ZP (expressed in R_2) of a point to be transferred.

These coordinates can be obtained by means of the tactile tip **30** for example. The procedure **2020** is followed by a procedure **2021** for calculating the corresponding coordinates XM, YM, ZM in R_1 through the transformation:

{XM, YM, ZM}=N*M^{-1}*{XP, YP, ZP}

A procedure **2022** next makes it possible to effect the displaying of the point with coordinates XM, YM, ZM on the model or again of a straight line or of a plane passing through this point and furthermore meeting other criteria.

It will be noted here that the two sub-modules **201**, **202** can used [sic] by the surgeon at any moment for the purpose of checking the valid nature of the transfer tools; in particular, it is possible to check at any time that a real base point, with coordinates known both in R_2 and R_1 (for example a base point of SR or an arbitrary notable point of the structure SNH visible on the images), correctly relocates with respect to its image after transferring the coordinates in step **2011**.

In the event of an excessive difference, a new step of elaboration of the transfer tools is performed.

Furthermore, the sub-modules **201**, **202** can be designed to also integrate the taking into account of the residual uncertainty, as spoken of above, so as for example to represent on the screen a point sensed not in a pointwise manner, but in the form for example of a circle or a sphere representing the said uncertainty.

From a simulated intervention path, for example on the representation RSNH, or from any other straight line selected by the surgeon, the invention furthermore enables the model to be represented on the screen from a viewpoint corresponding to this straight line. Thus the third transfer subroutine comprises, as represented in FIGS. *9a* and *9b*, a first module **301** for visualizing the representation in a direction given by two points and a second module **302** for visualizing the representation in a direction given by an angle of elevation and an angle of azimuth.

The first module **301** for visualizing the representation in a direction given by two points comprises a first sub-module denoted **3010** permitting acquisition of the two relevant points which will define the selected direction. The coordinates of these points are expressed in the reference frame R_1, these points having either been acquired previously on the nonhomogeneous structure SNH for example by means of the tactile tip **30** and then subjected to the reference frame transfer, or chosen directly on the representation by means of the graphics interface of the "mouse" type.

The first sub-module **3010** is followed by a second sub-module denoted **3011** permitting the creation of a unit, orthogonal three-dimensional matrix V characteristic of a right-handed orthonormal basis $\vec{i}''$, $\vec{j}''$, $\vec{k}''$ the unit vectors $\vec{i}''$, $\vec{j}''$, $\vec{k}''$, being determined through the relations:

$$\vec{k}'' = \vec{AB}/\|\vec{AB}\|;$$

$$\vec{i}'' \cdot \vec{k}'' = O; \vec{i}'' \cdot \vec{z}'' = O; \|\vec{i}''\| = 1;$$

$$\vec{j}'' = \vec{k}'' \Lambda \vec{j}''$$

where "Λ" represents the vector product and "." symbolizes the scalar product.

The sub-module **3011** is followed by a routine **3012** making it possible to secure for all the points of the entities (structures of interest) of the three-dimensional data base of coordinates XW, YW, ZW in R_1 a conversion into the orthonormal basis ($\vec{i}''$, $\vec{j}''$, $\vec{k}''$) by the relation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The subroutine **3013** is then followed by a subroutine **3014** for displaying the plane i", j", the subroutines **3013** and **3014** being called up for all the points, as symbolized by the arrow returning to block **3012** in FIG. *9a*.

When all the points have been processed, an output module **3015** permits return to a general module, which will be described later in the description. It is understood that this module enables two-dimensional images to be reconstructed in planes perpendicular to the direction defined by A and B.

In the same way, the second module **302** (FIG. *9b*) for visualizing the representation from a viewpoint given by an angle of elevation and an angle of azimuth comprises a first sub-module **3020** for acquiring the two angles in the representation frame of reference.

The selection of the angles of elevation and of azimuth can be made by selecting from a predefined data base or by moving software cursers associated with each view or else by modification relative to a current direction, such as the modeled direction of intervention. The sub-module **3020** is itself followed by a second sub-module **3021** for creating a unit orthoganal three-dimensional matrix W characteristic of a right-handed orthonormal basis of unit vectors $\vec{i}'''$, $\vec{j}'''$, $\vec{k}'''$. They are defined by the relations:

$$\vec{i}''' \cdot \vec{k}''' = O;$$

$$\vec{k}''' \cdot \vec{z}''' = \sin(\text{azimuth})$$

$$\vec{j}''' \cdot \vec{z}''' = O;$$

$$\vec{i}''' \cdot \vec{y} = \cos(\text{elevation});$$

$$\vec{i}'''' \cdot \vec{x}''' = \sin(\text{elevation})$$

$$\vec{j}''' = \vec{k}''' \wedge \vec{i}'''$$

A routine **3022** is then called for all the points of the entities of the three-dimensional data base of coordinates XW, YW, ZW and enables a first sub-routine **3023** to be called permitting calculation of the coordinates of the relevant point in the right-handed orthonormal bases $\vec{i}'''$, $\vec{j}'''$ $\vec{k}'''$ through the transformation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The sub-routine **3023** is itself followed by a sub-routine **3024** for displaying the plane i''', j''', the two sub-routines **3023** and **3024** then being called up for each point as symbolized by the return via the arrow to the block **3022** for calling the abovementioned routine. When all the points have been processed, an output sub-module **3025** permits a return to the general menu.

Of course, all of the programs, sub-routines, modules, sub-modules and routines destroyed earlier are managed by a general "menu" type program so as to permit interactive driving of the system by screen dialogue with the intervening surgeon by specific screen pages.

A more specific description of a general flow diagram illustrating this general program will now be given in connection with FIGS. **10***a* and **10***b*.

Thus, in FIG. **10***a* has been represented in succession a screen page **4000** relating to the loading of data from the digitized file **10**, followed by a screen page **4001** making it possible to secure the parameterizing of the grey scales of the display on the dynamic display means **1** and to calibrate the image, for example.

The screen page **4001** is followed by a screen page **4002** making it possible to effect the generation of a global view and then a step or screen page **4003** makes it possible to effect an automatic distribution of the sections on the screen of the workstation.

A screen page **4004** makes it possible to effect a manual selection of sections and then a screen page **4005** makes it possible to effect the selection of the strategy (search for the entry points and for the possible directions of intervention, first localizing of the target (tumor . . .) to be treated . . .), as defined earlier, and to select the position and horizontal, sagittal and frontal distribution of the sections.

A screen page **4006** also makes it possible to effect a display of the settings of a possible stereotaxic frame.

It will be recalled that the reference structure SR advantageously replaces the stereotaxic frame formerly used to effect the marking of position inside the patient's skull.

There may furthermore be provided a screen-page **4007** for choosing strategic sections by three-dimensional viewing, on selection by the surgeon, and then at **4008** the aligning of the references of the peripherals (tool, sighting members, etc., with the aid of the probe **30**.

A screen page **4009** is also provided to effect the search for the base points on the patient with the aid of the said probe, following which the steps of construction of the reference frame transfer tools and of actual reference frame transfer are performed, preferably in a user-transparent manner.

Another screen page **4010** is then provided, so as to effect the localizing of the target on the representation (for example a tumor to be observed or treated in the case of a neurosurgical intervention) in order subsequently to determine a simulated intervention path.

Then a new screen page **4011** makes it possible to effect the setting of the guides for the tool on the basis of this simulated path before opening up the skin and bone flaps on the patient's skull.

Then a new localizing step **4012** makes it possible to check whether the position of the guides corresponds correctly to the simulated intervention path.

The screen page **4012** is followed by a so-called intervention screen page, the intervention being performed in accordance with step **1110** of FIG. *5b*.

A more detailed description of the interactive dialogue between the surgeon and the system during a surgical, and in particular a neurosurgical, intervention will follow with reference to FIG. **10***c* and to all of the preceding description.

The steps of FIG. **10***c* are also integrated in the general program mentioned earlier; there are undertaken in succession a first phase I (preparation of the intervention), then a second phase II, (prior to the actual intervention, the patient is placed in a condition for intervention, the reference structure SR being tied to the second reference frame R_2), then a third phase III (intervention) and finally a post-intervention phase IV.

With a view to preparing the intervention, the system requests the surgeon (step **5000**) to choose the elementary structures of interest (for example bones of the skull, ventricles, vascular regions, the tumor to be explored or treated, and the images of the marks constituting in the first reference frame the representation RSR).

The choice of the elementary structures of interest is made on the display of the tomographic images, for example, called up from the digitized file **10**.

The system next performs, at step **5001**, a modeling of the structures of interest, as described earlier. Then, the nonhomogeneous structure having been thus constituted as a three-dimensional model RSNH displayed on the screen, the intervening surgeon is then led to perform a simulation by three-dimensional imaging, at step **5002**, with a view to defining the intervention path of the tool **50**.

During phase II the patient being placed in a condition for intervention and his head and the reference structure SR being tied to the second reference frame R_2, the surgeon performs at step **5003** a search for the position of the marks M1 to M4 constituting base points of the reference structure in the second reference frame R_2, and then during a step **5004**, performs a search for the position of the sighting systems, visualizing member OV, or of the tools and intervention instruments **50**, still in the second reference frame R_2, so as, if appropriate, to align these implements with respect to R_2.

The system then performs the validation of the intervention/patient spaces and representation by three-dimensional imaging in order to determine next the common origin of intervention ORI. In other words, the matrix reference frame transfer described above is supplemented with the necessary origin translations (origins **01** and **02** aligned on ORI).

This operation is performed as described earlier.

Phase III corresponds to the intervention, during which the system effects at step **5006** a permanent coupling in real time between the direction of aim of the active member **50**, and/or of the direction of aim of the sighting member OV (and if appropriate of the laser beam), with the direction of aim (of observation) simulated by three-dimensional imaging on the display means **1**, and vice versa.

In the following step **5007**, the coupling is effected of the movements and motions of the intervention instrument with their movements simulated by three-dimensional imaging, with automatic or manual conduct of the intervention.

As noted at **5008**, the surgeon can be supplied with a permanent display of the original two-dimensional sectional images in planes specified with respect to the origin ORI and to the direction of intervention. Such a display enables the surgeon at any time to follow the progress of the intervention in real time and to be assured that the intervention is proceeding in accordance with the simulated intervention. In phase IV which is executed after the intervention, the system effects a saving of the data acquired during the intervention, this saving making it possible subsequently to effect a comparison in real time or deferred in the event of successive interventions on the same patient.

Furthermore, the saved data make it possible to effect a playback of the operations carried out with the option of detailing and supplementing the regions traversed by the active member **50**.

Thus, a particularly powerful interactive system for local intervention has been described.

Thus, the system which is the subject of the present invention makes it possible to represent a model containing only the essential structures of the nonhomogeneous structure, this facilitating the work of preparation and of monitoring of the intervention by the surgeon.

Moreover, the system, by virtue of the algorithms used and in particular by minimizing the distortion between the real base points and their images in the 2D sections or the maps, makes it possible to establish a two-way coupling between the real world and the computer world through which the transfer errors are minimized, making possible concrete exploitation of the imaging data in order to steer the intervention tool.

To summarize, the system makes possible an ineractive [sic] medical usage not only to create a three-dimensional model of the nonhomogeneous structure but also to permit a marking in real time with respect to the internal structures and to guide the surgeon in the intervention phase.

More generally, the invention makes it possible to end up with a coherent system in respect of:

- the two-dimensional imaging data (scanner sections, maps, etc.)
- the three-dimensional data base;
- the data supplied by the marker means **3** in the reference frame R_2;
- the coordinate data for the sighting systems and intervention tools;
- the real world of the patient on the operating table.

Accordingly, the options offered by the system are, in a non-limiting manner, the following:

- the tools and of [sic] their position can be represented on the screen;
- the position of a point on the screen can be materialized on the patient for example with the aid of the laser emission device EL;
- the orientation and the path of a tool such as a needle can be represented on the screen and materialized on the patient optically (laser emission) or mechanically (positioning of the guide-arm in which the tool is guided in translation):
- an image of the patient, yielded for example by a system for taking pictures if appropriate in relief, can be superimposed on the three-dimensional representation modeled on the screen; thus, any change in the soft external parts of the patient can be visualized as compared with the capture by the scanner;
- it being possible for the surgeon's field of view given by a sighting member (such as a surgical microscope) to be referenced with respect to R_2, the direction of visualization of the model on the screen can be made identical to the real sight by the sighting member;
- finally, the three-dimensional images, normally displayed on the screen in the preceding description, may as a variant be introduced into the surgeon's microscope so as to obtain the superposition of the real image and the representation of the model.

We claim:

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

- means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;
- means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;
- means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;
- means for determining a set of coordinates of the plurality of base points in the second reference frame;
- means of intervention comprising an active member whose position is determined with respect to the second reference frame;
- means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;
- means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,
- means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim **1**, wherein the plurality of reference frame translation tools comprise:

- means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;
- means for creating a matrix (N) for transferring between the second reference frame and a second intermediate

reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

$\{YP, YP, ZP\}=M*N^{-1} *\{XM, YM, ZM\}$ where $M * N^{-1}$ represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

$\{YM, YM, ZM\}=N*M^{-1} *\{XP, ZP, ZP\}$ where $N*M^{-1}$ represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.: 5,868,675

DATED: February 9, 1999

INVENTOR(S): Henrion et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Title, item [54], delete "NONHUMOGENEOUS STRUCTURE" and insert — NON-HOMOGENEOUS STRUCTURE --.

At item [22], the PCT filing date, delete "May 10, 1990" and insert — October 5, 1990 --.

Signed and Sealed this

Eighth Day of May, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

LISTING OF CLAIMS

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;

means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;

means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;

means for determining a set of coordinates of the plurality of base points in the second reference frame;

means of intervention comprising an active member whose position is determined with respect to the second reference frame;

means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference

frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;

means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,

means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim 1, wherein the plurality of reference frame translation tools comprise:

means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;

means for creating a matrix (N) for transferring between the second reference frame and a second intermediate reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

{YP,YP, ZP}=M*N.sup.-1 *{XM,YM,ZM} where M * N.sup.-1 represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

{YM, YM, ZM}=N*M.sup.-1 *{XP,ZP,ZP} where N*M.sup.-1 represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

17. (Canceled)

18. (Canceled)

19. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention; and

a tracking system operable to determine a position of at least the second reference structure and a position of the active member and configured to transmit the determined positions of the second reference structure and the active member to the controller;

wherein the controller is configured to determine the position of the active member based on the determined position of at least the active member and the correlation of the first reference structure and the second reference structure.

20. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure includes a plurality of base points.

21. (previously presented) The interactive system as defined in Claim 20 wherein the second reference structure includes a plurality of tracking markers.

22. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure includes a plurality of tracking markers.

23. (previously presented) The interactive system as defined in Claim 22 wherein the plurality of tracking markers are attached to the patient.

24. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is attached to the patient.

25. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is attached to the patient.

26. (previously presented) The interactive system as defined in Claim 21 wherein the plurality of base points are generated from the plurality of tracking markers.

27. (previously presented) The interactive system as defined in Claim 20 wherein the plurality of base points are at least one of a plurality of notable points on the patient and marks fixed to the patient.

28. (previously presented) The interactive system as defined in Claim 27 wherein the notable points are selected from a group comprising a head, eyebrows, temples, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

29. (previously presented) The interactive system as defined in Claim 19 wherein the tracking system includes a marker device operable to determine a position of the second reference structure in relation to the patient reference frame.

30. (Amended) The interactive system as defined in Claim 29 wherein the marker device includes a telemetry system operable to determine the position of the second reference structure in the patient reference frame and transmit the determined position to the controller, wherein the controller is operable to perform the correlation at least with the transmitted determined position.

31. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an electromagnetic telemetry system.

32. (previously presented) The interactive system as defined in Claim 31 wherein the second reference structure includes electromagnetic tracking markers, wherein the electromagnetic telemetry system is operable to determine the position of the electromagnetic tracking markers of the second reference structure in relation to the patient reference frame.

33. (previously presented) The interactive system as defined in Claim 32, wherein the electromagnetic tracking markers are transmitters and the electromagnetic telemetry system is an electromagnetic sensor.

34. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an optical telemetry system.

35. (Amended) The interactive system as defined in Claim 34 wherein the optical telemetry system includes at least one of a video camera or an infrared camera to image at least the second reference structure and configured to plot points of the second reference structure.

36. (previously presented) The interactive system as defined in Claim 34 wherein the second reference structure includes optical tracking markers, wherein the optical telemetry system is operable to determine the position of the optical tracking markers of the second reference structure in relation to the patient reference frame.

37. (previously presented) The interactive system as defined in Claim 34 wherein the optical telemetry system utilizes position and shape recognition to identify the second reference structure.

38. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a three-dimensional probe.

39. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe includes a tactile tip operable to engage the second reference structure.

40. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe is robotically manipulated, such that the instantaneous position of the three-dimensional probe is known.

41. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a set of cameras operable to determine the position of the second reference structure in relation to the patient reference frame.

42. (previously presented) The interactive system as defined in Claim 41 wherein the set of cameras are selected from video and infrared cameras.

43. (previously presented) The interactive system as defined in Claim 29 wherein the marker device is a laser beam emission system operable to illuminate the second reference structure to determine a position of the second reference structure in relation to the patient reference frame.

44. (previously presented) The interactive system as defined in Claim 20 wherein the controller further includes a graphical tool operable to identify the plurality of

base points of the first reference structure in the image data of the image data reference frame.

45. (previously presented) The interactive system as defined in Claim 44 wherein the graphical tool is a mouse in communication with the controller.

46. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is generated from the second reference structure.

47. (canceled)

48. (Amended) The interactive system as defined in Claim 19 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

49. (Amended) The interactive system as defined in Claim 19 further comprising a telemetry system operable to determine the position of the active member in the patient reference frame, said telemetry system in communication with the controller.

50. (previously presented) The interactive system as defined in Claim 49 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

51. (Amended) The interactive system as defined in Claim [[47]] 19 wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame.

52. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

53. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to model a reference origin of intervention and a direction of intervention and said display is further operable to display the modeled reference origin of intervention and direction of intervention.

54. (Amended) The interactive system as defined in Claim 51 wherein the display is further operable to display the real-time position of the active member in the image reference frame based on the determined position of the active member with the tracking system.

55. (previously presented) The interactive system as defined in Claim 51 wherein the display is further operable to display image data relative to a direction of intervention of the active member.

56. (previously presented) The interactive system as defined in Claim 55 wherein the image data is displayed perpendicular to a direction of intervention of the active member.

57. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to simulate an optimal trajectory of advance of the active member and said display is operable to display the optimal trajectory in the image data relative to the image reference frame.

58. (previously presented) The interactive system as defined in Claim 57 wherein movement of the active member is steered to the optimal trajectory to carry out a programmed intervention.

59. (Amended) The interactive system as defined in Claim 19 wherein the active member is robotically controlled.

60. (previously presented) The interactive system as defined in Claim 19 wherein the image data is at least one of a magnetic resonance image data, a

tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

61. (previously presented) The interactive system as defined in Claim 19 wherein the device is operable to construct three-dimensional images from captured two-dimensional images.

62. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient; and

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

wherein the device is operable to construct three-dimensional images from captured two-dimensional images;

wherein the controller is operable to superimpose two-dimensional image data on the three-dimensional images wherein any change in soft external parts of the patient can be visualized as compared with the image captured by the imaging device.

63. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame; and

an active member operable to perform the intervention;

wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame;

wherein the controller is further operable to determine residual uncertainty which is used to represent a contour with dimensions larger than those which would normally be represented and the display is operable to display the residual uncertainty of the contour.

64. (previously presented) The interactive system as defined in Claim 63 wherein the contour is a display of an active member and a representation of residual uncertainty in order to reduce the chance of traversing undesired structures.

65. (previously presented) The interactive system as defined in Claim 19 wherein the controller is further operable to correlate map data in a map reference frame with the patient reference frame.

66. (Amended) The interactive system as defined in Claim 19 wherein the intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

67. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is fixed to a head set.

68. (previously presented) The interactive system as defined in Claim 60 wherein the head set is further fixed to an operating table.

69. (previously presented) The interactive system as defined in Claim 19 wherein the device further includes memory operable to store the image data.

70. (previously presented) The interactive system as defined in Claim 19 wherein the device is a first computer.

71. (previously presented) The interactive system as defined in Claim 70 wherein the controller is a second computer.

72. (previously presented) The interactive system as defined in Claim 71 wherein the first computer and the second computer is a single work station.

73. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention inside the region of the patient;

a tracking system operable to track the position of the active member in relation to the patient reference frame, the tracking system being in communication with the controller to transmit the tracked position of the active member as position information to the controller, wherein the controller is operable to determine the position of the active member relative to the image reference frame; and

a display operable to display the real-time position of the active member in the image reference frame based on the controller determined position of the active member based on the tracked position of the active member from the tracking system, wherein the controller is configured to generate a representation of the active member that is displayed on the display relative to a display of the received image data.

74. (previously presented) The interactive system as defined in Claim 73 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

75. (previously presented) The interactive system as defined in Claim 73 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

76. (previously presented) The interactive system as defined in Claim 73 wherein the tracking system that tracks the position of the active member is a telemetry system in communication with the controller.

77. (previously presented) The interactive system as defined in Claim 73 wherein the active member is robotically controlled.

78. (previously presented) The interactive system as defined in Claim 73 wherein the image data is at least one of a magnetic resonance image data, a tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

79. (previously presented) The interactive system as defined in Claim 73 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

80. (previously presented) The interactive system as defined in Claim 73 wherein the first reference structure includes a plurality of base points.

81. (previously presented) The interactive system as defined in Claim 80 wherein the second reference structure includes a plurality of tracking markers.

82. (previously presented) The interactive system as defined in Claim 81 wherein the plurality of base points are generated by the plurality of tracking markers.

83. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is attached to the patient.

84. (previously presented) The interactive system as defined in Claim 73 wherein intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery intervention, and combinations thereof.

85. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is fixed to a head set.

<u>86. (Amended) The interactive system as defined in Claim 73 wherein the display forms part of the device and wherein the image data received is acquired image data of the region of the patient and is displayed on the display, further wherein the representation of the active member is displayed on the acquired image data of the region of the patient.</u>

87. (Twice Amended) A method for performing an image guided intervention inside a region of a patient, said method comprising:

accessing a first image data of the region of the patient captured with an imaging system where the first image data includes image data of a first reference structure;

identifying the first reference structure in the first image data to establish an image reference frame;

identifying a second reference structure relative to the patient to establish a patient reference frame;

correlating the position of the first reference structure in the image reference frame in the first image data with the position of the second reference structure in the patient reference frame; and

tracking an active member at least to determine a position of the active member in the patient reference frame to determine a location of the active member based on the tracking of the active member and transmitting the determined position in the patient refrence frame for display on a display device relative to the image reference frame of the first image data based at least on the correlation of the first reference structure and the second reference structure.

88. (previously presented) The method as defined in Claim 87 further comprising attaching a plurality of tracking markers to the patient where the tracking markers form the second reference structure.

89. (previously presented) The method as defined in Claim 88 further comprising identifying the position of the tracking markers in the patient reference frame using a telemetry system.

90. (Amended) The method as defined in Claim 89 further comprising transmitting from the tracking markers a signal and receiving the transmitted signal with an electromagnetic sensor to identify the position of the second reference structure in the patient reference frame.

91. (previously presented) The method as defined in Claim 87 wherein identifying the first reference structure includes identifying a plurality of base points visible in the image data.

92. (previously presented) The method as defined in Claim 91 wherein identifying the plurality of base points includes identifying at least one of notable points on the patient as marks fixed to the patient representing the plurality of base points.

93. (previously presented) The method as defined in Claim 92 wherein the notable points are selected from a group comprising a head, eyebrows, temporal point, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

94. (previously presented) The method as defined in Claim 91 wherein the plurality of base points visible in the image data are generated from the plurality of tracking markers attached to the patient.

95. (previously presented) The method as defined in Claim 87 further comprising attaching the second reference structure to the patient.

96. (previously presented) The method as defined in Claim 87 further comprising displaying the image data of the region of the patient, including displaying the first reference structure.

97. (previously presented) The method as defined in Claim 87 further comprising performing an intervention on the patient with an active member.

98. (Canceled)

99. (Amended) The method as defined in Claim 96 further comprising:

displaying the position of the active member as a representation of the active member in the accessed first image data that is captured image data that is correlated to the patient based on the correlation and displayed on a display device with the position of the active member being correlated between the patient reference frame defined by the first reference structure fixed to the patient and the image reference frame based on the tracking of the active member.

100. (Amended) The method as defined in Claim 99 further comprising identifying the position of the active member with a telemetry system by transmitting the tracked location of the active member for displaying the representation of the active member.

101. (previously presented) The method as defined in Claim 99 further comprising displaying a reference origin of intervention and a direction of intervention in the image data.

102. (previously presented) The method as defined in Claim 101 further comprising tracking the position of the active member relative to the reference origin of intervention and the direction of intervention.

103. (previously presented) The method as defined in Claim 87 further comprising converting two-dimensional image data to three-dimensional image data.

104. (previously presented) The method as defined in Claim 97 wherein the intervention is selected from at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

105. (previously presented) The method as defined in Claim 95 further comprising attaching the second reference structure to a head set.

ATTACHMENT J

Taylor, Michael

From:	Taylor, Michael
Sent:	Wednesday, November 09, 2011 3:30 PM
To:	'nchdoul@fo-rothschild.fr'; 'jbthiebaut@fo-rothschild.fr'; 'Joel.henrion@wanadoo.fr'; 'Jf.uhl@free.fr'; 'Michel Scriban'; 'jf.uhl@wanadoo.fr'; 'jef.uhl@gmail.com'; 'm.scriban@nelixa.com'
Cc:	Warner, Rick; Hall, Stephanie; Neal, Patrick
Subject:	RE: Response Required November 14, 2011 - Re-issue of U.S. Patent No. 5,868,675 (5074a-000013/REA) [HDP-Troy_Legal.FID2452556]
Attachments:	DHL_tracking_sent_Nov-1-2011 (all).PDF

Dear Michel Scriban, Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut:

Attached is a tracking list from DHL indicating that the packages we sent were delivered and signed for on November 3, 2011.

This is a reminder that we requested the executed Supplemental Reissue Declaration by November 14, 2011 to respond in good time to the U.S. Patent Office.

Best Regards,

Michael Taylor

HARNESS DICKEY
Michael L. Taylor | Patent Attorney
O | 248.641.1600 **F** | 248.641.0270 **D** | 248.641.1289
IP Causes Worldwide

From: Taylor, Michael
Sent: Tuesday, November 01, 2011 4:10 PM
To: 'jbthiebaut@fo-rothschild.fr'; 'Joel.henrion@wanadoo.fr'; 'Jf.uhl@free.fr'; 'Michel Scriban'; 'jf.uhl@wanadoo.fr'
Cc: Warner, Rick; Hall, Stephanie; Neal, Patrick
Subject: Response Required November 14, 2011 - Re-issue of U.S. Patent No. 5,868,675 (5074a-000013/REA) [HDP-Troy_Legal.FID2452556]
Importance: High

Michel Scriban
72 Chemin de Crapon
69360 Ternay, France
m.scriban@nelixa.fr

Joel Henrion
17, Route de Chalone
51600 Suippes, France
Joel.henrion@wanadoo.fr

Jean Francois UHL
199 avenue du Maine
Paris, France 75014

Jf.uhl@free.fr and Jf.uhl@wanadoo.fr

Jean-Baptiste Thiebaut
42 boulevard Saint-Marcel
Paris, France 75005
jbthiebaut@fo-rothschild.fr

Dear Sirs,

The attached documents are for your review, consideration, execution, and return to us. We are also sending paper copies to the addresses noted above.

We thank you for your consideration and look forward to you swift response.

Sincerely,

Michael L. Taylor

Michael L. Taylor
Patent Attorney

Office: 248.641.1600
Fax: 248.641.0270
Direct: 248.641.1289

HARNESS DICKEY
IP Causes Worldwide

5445 Corporate Dr, Suite 200
Troy, MI 48098

Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

English Contact Center Tools Country Profile

Track DHL Express Shipments

DHL's online tracking is the fastest way to find out where your shipment is. No need to call Customer Service when we can offer you real-time details of your shipment's progress as it speeds through the DHL Network on the way to its destination.

Print Now

Result Summary **Show All**

Waybill: 8809998164
Signed for by: TEIXEIRA

Thursday, November 03, 2011 at 10:06
Origin Service Area: › ROMULUS, MI - TROY - USA

Destination Service Area: › ORLY - PARIS - FRANCE

	Thursday, November 03, 2011	**Location**	**Time**
11	Delivered - Signed for by : TEIXEIRA	ORLY - FRANCE	10:06
10	With delivery courier	ORLY - FRANCE	08:48
9	Arrived at Sort Facility ORLY - FRANCE	ORLY - FRANCE	02:41
8	Departed Facility in PARIS - FRANCE	PARIS - FRANCE	00:50
	Wednesday, November 02, 2011	**Location**	**Time**
7	Processed at PARIS - FRANCE	PARIS - FRANCE	20:22
6	Departed Facility in CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	05:23
5	Processed at CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	04:24
4	Arrived at Sort Facility CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	02:37
	Tuesday, November 01, 2011	**Location**	**Time**
3	Departed Facility in ROMULUS - USA	ROMULUS, MI - USA	23:37
2	Processed at ROMULUS - USA	ROMULUS, MI - USA	23:36
1	Shipment picked up	ROMULUS, MI - USA	17:50

Hide Details

Waybill: 8809998153
Signed for by: RNMJ

Thursday, November 03, 2011 at 11:41
Origin Service Area: › ROMULUS, MI - TROY - USA

Destination Service Area: › ORLY - PARIS - FRANCE

	Thursday, November 03, 2011	**Location**	**Time**
11	Delivered - Signed for by : RNMJ	ORLY - FRANCE	11:41
10	With delivery courier	ORLY - FRANCE	07:31
9	Arrived at Sort Facility ORLY - FRANCE	ORLY - FRANCE	02:41
8	Departed Facility in PARIS - FRANCE	PARIS - FRANCE	00:50
	Wednesday, November 02, 2011	**Location**	**Time**
7	Processed at PARIS - FRANCE	PARIS - FRANCE	20:22
6	Departed Facility in CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	05:23
5	Processed at CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	04:24
4	Arrived at Sort Facility CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	02:37
	Tuesday, November 01, 2011	**Location**	**Time**
3	Departed Facility in ROMULUS - USA	ROMULUS, MI - USA	23:37
2	Processed at ROMULUS - USA	ROMULUS, MI - USA	23:36
1	Shipment picked up	ROMULUS, MI - USA	17:50

Hide Details

Waybill: 8809998142
Signed for by: HENION

Thursday, November 03, 2011 at 14:04
Origin Service Area: › ROMULUS, MI - TROY - USA

Destination Service Area: › ORLY - SUIPPES - FRANCE

FRANCE

Thursday, November 03, 2011		Location	Time
14	Delivered - Signed for by : HENION	ORLY - FRANCE	14:04
[illegible]	[illegible]urier	ORLY - FRANCE	10:07
12	Arrived at Delivery Facility in ORLY - FRANCE	ORLY - FRANCE	09:31
11	Departed Facility in ORLY - FRANCE	ORLY - FRANCE	07:58
10	Processed at ORLY - FRANCE	ORLY - FRANCE	04:18
9	Arrived at Sort Facility ORLY - FRANCE	ORLY - FRANCE	02:41
8	Departed Facility in PARIS - FRANCE	PARIS - FRANCE	00:50

Wednesday, November 02, 2011		Location	Time
7	Processed at PARIS - FRANCE	PARIS - FRANCE	20:22
6	Departed Facility in CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	05:23
5	Processed at CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	04:24
4	Arrived at Sort Facility CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	02:37

Tuesday, November 01, 2011		Location	Time
3	Departed Facility in ROMULUS - USA	ROMULUS, MI - USA	23:37
2	Processed at ROMULUS - USA	ROMULUS, MI - USA	23:36
1	Shipment picked up	ROMULUS, MI - USA	17:50

Hide Details

Waybill: 8809998131

✓ **Signed for by: SCRIBAN**

Thursday, November 03, 2011 at 14:23
Origin Service Area: › ROMULUS, MI - TROY - USA

Destination Service Area: › LYON - TERNAY - FRANCE

Thursday, November 03, 2011		Location	Time
15	Delivered - Signed for by : SCRIBAN	LYON - FRANCE	14:23
14	With delivery courier	LYON - FRANCE	09:48
13	Arrived at Delivery Facility in LYON - FRANCE	LYON - FRANCE	08:11
12	Departed Facility in LYON - FRANCE	LYON - FRANCE	07:37
11	Processed at LYON - FRANCE	LYON - FRANCE	06:18
10	Arrived at Sort Facility LYON - FRANCE	LYON - FRANCE	05:58
9	Departed Facility in LEIPZIG - GERMANY	LEIPZIG - GERMANY	03:37
8	Processed at LEIPZIG - GERMANY	LEIPZIG - GERMANY	00:22

Wednesday, November 02, 2011		Location	Time
7	Arrived at Sort Facility LEIPZIG - GERMANY	LEIPZIG - GERMANY	23:08
6	Departed Facility in CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	08:48
5	Processed at CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	05:09
4	Arrived at Sort Facility CINCINNATI HUB - USA	CINCINNATI HUB, OH - USA	02:37

Tuesday, November 01, 2011		Location	Time
3	Departed Facility in ROMULUS - USA	ROMULUS, MI - USA	23:37
2	Processed at ROMULUS - USA	ROMULUS, MI - USA	23:36
1	Shipment picked up	ROMULUS, MI - USA	17:50

Hide Details

ATTACHMENT K

Taylor, Michael

From: Joel HENRION <joel.henrion@wanadoo.fr>
Sent: Thursday, November 10, 2011 1:58 AM
To: Taylor, Michael; 'nchdoul@fo-rothschild.fr'
Cc: Warner, Rick; Hall, Stephanie; Neal, Patrick
Subject: RE: Response Required November 14, 2011 - Re-issue of U.S. Patent No. 5,868,675 (5074a-000013/REA) [HDP-Troy_Legal.FID2452556]
Attachments: DHL_tracking_sent_Nov-1-2011_-all-.PDF

Je vous prie de prendre connaissance de ma remarque sur le document PDF joint a cet envoi...

Cordialement, Joel HENRION

> Message du 09/11/11 21:30
> De : "Taylor, Michael"
> A : "'nchdoul@fo-rothschild.fr'" , "'jbthiebaut@fo-rothschild.fr'" , "'Joel.henrion@wanadoo.fr'" <'Joel.henrion@wanadoo.fr>, "'Jf.uhl@free.fr'" <'Jf.uhl@free.fr>, "'Michel Scriban'" , "'jf.uhl@wanadoo.fr'" , "'jef.uhl@gmail.com'" , "'m.scriban@nelixa.com'"
> Copie à : "Warner, Rick" , "Hall, Stephanie" , "Neal, Patrick"
> Objet : RE: Response Required November 14, 2011 - Re-issue of U.S. Patent No. 5,868,675 (5074a-000013/REA) [HDP-Troy_Legal.FID2452556]
>
>

Dear Michel Scriban, Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut:
Attached is a tracking list from DHL indicating that the packages we sent were delivered and signed for on November 3, 2011.
This is a reminder that we requested the executed Supplemental Reissue Declaration by November 14, 2011 to respond in good time to the U.S. Patent Office.
Best Regards,
Michael Taylor

HARNESS DICKEY
Michael L. Taylor | Patent Attorney
> O | 248.641.1600 F | 248.641.0270 D | 248.641.1289
> IP Causes Worldwide

From: Taylor, Michael
> **Sent:** Tuesday, November 01, 2011 4:10 PM
> **To:** 'jbthiebaut@fo-rothschild.fr'; 'Joel.henrion@wanadoo.fr'; 'Jf.uhl@free.fr'; 'Michel Scriban'; 'jf.uhl@wanadoo.fr'
> **Cc:** Warner, Rick; Hall, Stephanie; Neal, Patrick
> **Subject:** Response Required November 14, 2011 - Re-issue of U.S. Patent No. 5,868,675 (5074a-000013/REA) [HDP-Troy_Legal.FID2452556]
> **Importance:** High

Michel Scriban
72 Chemin de Crapon
69360 Ternay, France
m.scriban@nelixa.fr

Joel Henrion
17, Route de Chalone
51600 Suippes, France
Joel.henrion@wanadoo.fr

Jean Francois UHL
199 avenue du Maine
Paris, France 75014
Jf.uhl@free.fr and Jf.uhl@wanadoo.fr

Jean-Baptiste Thiebaut
42 boulevard Saint-Marcel
Paris, France 75005
jbthiebaut@fo-rothschild.fr

Dear Sirs,

The attached documents are for your review, consideration, execution, and return to us. We are also sending paper copies to the addresses noted above.

We thank you for your consideration and look forward to you swift response.

Sincerely,

Michael L. Taylor

Michael L. Taylor
> Patent Attorney

Office: 248.641.1600
> Fax: > 248.641.0270
> Direct: > 248.641.1289

> 5445 Corporate Dr, Suite 200
> Troy, MI 48098

HARNESS DICKEY

IP Causes Worldwide

Bio • vCard

Metropolitan | Detroit • Portland • St. Louis • Washington, DC

>
> [DHL_tracking_sent_Nov-1-2011 (all).PDF (48.3 Ko)]

ATTACHMENT L

Taylor, Michael

From: Sophie PONCET <sophie.ccgl@wanadoo.fr>
Sent: Tuesday, November 15, 2011 9:28 AM
To: Taylor, Michael
Cc: GRANGE Maxime
Subject: MEDTRONIC
Attachments: COURRIEL ME TAYLOR.pdf

Importance: High

Cher Monsieur,

Maître GRANGE, avocat au barreau de Lyon, répond à vos correspondances échangées notamment avec Michel SCRIBAN concernant le dossier en référence.

Nous restons dans l'attente de votre réponse.

Vous en remerciant par avance,

Nous vous adressons nos sentiments les plus dévoués.

Maxime GRANGE
ACCESS AVOCATS
63 avenue de Saxe - 69003 LYON
T 04 72 84 99 60
F 04 72 84 99 69

AVOCATS

A Lyon, le 15 novembre 2011

ACCESS AVOCATS
Selarl RCS Lyon en cours
Palais T 1635
Muriel LINARES
Avocat associée
Maxime GRANGE
Avocat associé

&

Christophe NEYRET - AVOCATS
Selarl 505 325 886 RCS Lyon
Palais - T 815

Membres d'une SCM

Ombeline SIRAUDIN
Avocat
Palais - T 176

Raphaël de PRAT
Avocat
Palais – T 1608

63 avenue de Saxe
69003 LYON

Tél : 04 72 84 99 60
Fax : 04 72 84 99 69

Monsieur Michaël TAYLOR

PAR MAIL : mltaylor@HDP.com

ATTENTION : nouvelle toque
Palais T 1635

🗁 : M SCRIBAN / HUL / THIEBAUT / HENRION – MEDTRONIC- MG/SP

Mon Cher Confrère,

J'interviens auprès de vous en ma qualité de conseil des inventeurs du brevet actuellement détenu par la société MEDTRONIC, que vous représentez.

J'ai pris connaissance de vos échanges de correspondances récents.

Pour le compte de MEDTRONIC, vous avez adressé à mes clients un dossier important, qui nécessite plusieurs jours d'étude par chacun des experts devant intervenir dans ce cadre.

Comme vous l'a indiqué Michel SCRIBAN le 9 octobre dernier, ce process va engager des frais importants, qui ne seraient pas normal de laisser à la charge des personnes que vous sollicitez.

En conséquence de ce qui précède, je vous remercie de m'indiquer si votre cliente accepte de couvrir le montant global de ces frais, d'un montant net de 70.800 € hors frais de séquestre.

Dans ce cadre, étant détenteur d'un compte spécial permettant le blocage de cette somme jusqu'à la finalisation de l'étude de votre dossier par mes clients, je vous propose d'intervenir à ce titre sur la base d'un montant forfaitaire de 4.200 €.

Le total représentera donc 75.000 €, séquestre inclus.

Dès que j'aurai reçu votre confirmation de l'accord de la société MEDTRONIC dans ce cadre, et que le virement de la somme nette de 75.000 € aura été constaté sur le compte séquestre ouvert auprès de la CARPA à LYON, ville du Barreau où je suis inscrits, l'étude des documents sera lancée sans aucun délai par mes clients et nous conviendront préalablement d'un délai de réponse à destination de votre cabinet.

Compte tenu de ce qui précède, je reste dans l'attente de vous lire,

Et vous prie de croire, Mon Cher Confrère, en mes sentiments les plus dévoués.

Maxime GRANGE

ATTACHMENT M

In Lyon, on November 15, 2011

Mr. Michael TAYLOR
By email : mltaylor@HDP.com

To : nouvelle toque
Palais T1635

Dear colleague,

I am addressing this letter to you in my capacity of Counsel of the inventors of the patent owned by the company MEDTRONIC, which you represent.

I have read the communications from the previous correspondences.

On behalf of MEDTRONIC, you have addressed to my clients an important file, which requires several days of study by each of the experts involved in this matter.

As Michel SCRIBAN mentioned to you on October 9 of this year, this process will incur significant costs, which shouldn't be at the charge of the people of whom you are seeking the assistance.

As a result of the foregoing, I would appreciate if you could let me know if your client agrees to cover the total amount of these expenses, a net amount of € 70,800 excluding costs of escrow.

About that, as I am the holder of a special account on which this amount can be blocked until the completion of the study of your file by my clients, I propose to act on this matter on the basis of a lump sum of € 4,200.

Such, the total of the expenses is € 75,000, including costs of escrow.

As soon as I receive your confirmation that MEDTRONIC agrees to the above, and when the transfer of the net sum of € 75,000 has been made to the escrow account opened with the CARPA in LYON, city of the bar in which I am enrolled, my clients will start the study of the documents without delay and we will prior agree on the delay in which we should send the answer to your practice.

Given the foregoing, I am looking forward to hearing from you.

Sincerely,
Maxime GRANGE

ATTACHMENT N

Taylor, Michael

From: Taylor, Michael
Sent: Wednesday, November 23, 2011 9:21 AM
To: 'Sophie PONCET'
Cc: 'GRANGE Maxime'; Warner, Rick; Neal, Patrick; Hall, Stephanie
Subject: RE: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]
Attachments: Current Claims.doc; Supplemental Reissue declaration.pdf; US 5868675.pdf; Assignment_Chain_USPTO.PDF; Assignment documnets (inventors to Diadex SA only) Medtronic, Inc..pdf; ltr to ALL inventors (English and French).PDF; ltr to atty Grange of inventors (dated Nov-22-2011.PDF

Cher GRANGE,

My email of yesterday appears to have been missing our letter. I apologize for this oversight. If you received our letter dated November 22, 2011 in yesterday's email, this email is a duplicate.

Best Regards,

Michael Taylor

HARNESS DICKEY
Michael L. Taylor | Patent Attorney
O | 248.641.1600 **F** | 248.641.0270 **D** | 248.641.1289
IP Causes Worldwide

From: Taylor, Michael
Sent: Tuesday, November 22, 2011 11:57 AM
To: 'Sophie PONCET'
Cc: GRANGE Maxime; Warner, Rick; Neal, Patrick; Hall, Stephanie
Subject: RE: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]

Cher GRANGE,

We understand that you are an attorney for all of Michel Scriban, Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut.

Please see our attached letter dated November 22, 2011, which refers to our previous correspondence, also attached.

Best Regards,

Michael Taylor

HARNESS DICKEY
Michael L. Taylor | Patent Attorney
O | 248.641.1600 **F** | 248.641.0270 **D** | 248.641.1289
IP Causes Worldwide

From: Sophie PONCET [mailto:sophie.ccgl@wanadoo.fr]
Sent: Tuesday, November 15, 2011 9:28 AM
To: Taylor, Michael
Cc: GRANGE Maxime
Subject: MEDTRONIC
Importance: High

Cher Monsieur,

Maître GRANGE, avocat au barreau de Lyon, répond à vos correspondances échangées notamment avec Michel SCRIBAN concernant le dossier en référence.

Nous restons dans l'attente de votre réponse.

Vous en remerciant par avance,

Nous vous adressons nos sentiments les plus dévoués.

Maxime GRANGE

ACCESS AVOCATS
63 avenue de Saxe - 69003 LYON
T 04 72 84 99 60
F 04 72 84 99 69

HARNESS DICKEY

Michael Taylor
Direct Dial: 248-641-1289
mltaylor@hdp.com

November 22, 2011

EMAIL ONLY

Acess Avocats
63 avenue de Saxe
69003, LYON
FRANCE

Re: U.S. reissue application 09/784,829 which is a Reissue of the U.S. Patent 5,868,675
Medtronic Ref. No. PC0000173.06
HDP Ref. No. 5074A-000013/REA

Dear Maxime Grange,

We have reviewed your correspondence of November 15, 2011 with our client, Medtronic, Inc.

Based on your letter, we understand that you represent **ALL** of the inventors Michel Scriban, Joel Henrion,
Jean Francois UHL, and Jean-Baptiste Thiebaut of the U.S. Pat. No. 5,868,675.

We have attached hereto our correspondence to all of the inventors sent on November 1, 2011 in which we requested the executed Supplemental Re-issue Declarations by November 14, 2011. As of this date we have **NOT** received any of the Supplemental Re-issue Declarations from any of the inventors.

Please note that in our previous correspondence we state "Medtronic notes that no payment is required under the assignment agreement that was executed by all of the inventors on June 22, 1992 and deems your request for payment a refusal to execute and return the Supplemental Reissue Declaration." Medtronic, Inc. maintains that no further payment is required per the original assignment of the invention disclosed in U.S. Pat. No. 5,868,675 from **ALL** of the inventors to DIADAX S.A. which, through proper assignment, now is owned by Medtronic, Inc.

Thank you in advance for your clients' cooperation in this matter, however, if we do not receive executed Supplemental Reissue Declarations from your clients (the inventors) by **November 28, 2011** Medtronic, Inc. will proceed in the U.S. Patent Office with a petition to continue prosecution based on the inventors refusal to sign the declarations.

Best Regards,

Michael L. Taylor, Esq.
Richard W. Warner, Esq.

Harness Dickey

Attachments

16414376.1

Sole or Joint USA Patent Appln. For inventions made outside USA

ASSIGNMENT

In consideration of the sum of One Dollar ($1.00) and other good and valuable consideration paid to each of the undersigned, to wit:

Insert Name(s) of Inventor(s)

(1) Joël HENRION (5) ______

(2) Michel SCRIBAN (6) ______

(3) Jean-Baptiste THIEBAUT (7) ______

(4) Jean-François UHL (8) ______

the receipt and sufficiency of which are hereby acknowledged by the undersigned who at the behest of, hereby sell(s), assign(s) and transfer(s) unto,

Insert Name of Assignee Address

DIADIX S.A. c/o AZAR S.A.
4 place de la Concorde - 75008 PARIS / FRANCE

(hereinafter designated "ASSIGNEE") the entire right, title and interest for the United States of America as defined in 35 U.S.C. 100, in the invention known as

Title of Invention

LOCAL INTERVENTION INTERACTIVE SYSTEM INSIDE A REGION OF A NON HOMOGENEOUS STRUCTURE

for which an application for Letters Patent of the United States of America has been executed even date herewith by the undersigned, and the undersigned hereby authorize(s) and request(s) the United States Commissioner of Patents and Trademark to issue said Letters Patent to the said ASSIGNEE, for its interest as ASSIGNEE, its successors, assigns and legal representatives; the undersigned agree(s) that the attorneys of record in said application shall hereafter act on behalf of said ASSIGNEE;

AND the undersigned hereby agree(s) to transfer a like interest, upon request of the said ASSIGNEE, its successors, assigns and legal representatives, and without further remuneration, in and to any and all divisions, continuations, substitutes, and reissues thereof; and to testify and execute any papers for ASSIGNEE, its successors, assigns and legal representatives, deemed essential by ASSIGNEE to ASSIGNEE'S full protection and title in and to the invention hereby transferred.

Please sign concurrently with application

Signed on the date(s) indicated beside my/our signature(s).

RECORDED
PATENT AND TRADEMARK OFFICE

INVENTOR(S)	DATE SIGNED	WITNESS(ES)
1) Name: Joël HENRION	Joël Henrion JUN 22 1992	Eric LE FORESTIER
2) Name: Michel SCRIBAN		
3) Name: Jean-Baptiste THIEBAUT	J.B. Thiebaut	
4) Name: Jean-François UHL		
5) Name:		
6) Name:		
7) Name:		
8) Name:		

REEL 6370 FRAME 0103

United States Patent and Trademark Office

Home | Site Index | Search | Guides | Contacts | eBusiness | eBiz alerts | News | Help

Assignments on the Web > Patent Query

Patent Assignment Abstract of Title

NOTE:Results display only for issued patents and published applications. For pending or abandoned applications please consult USPTO staff.

Total Assignments: 4

Patent #: 5868675 **Issue Dt:** 02/09/1999 **Application #:** 07847059 **Filing Dt:** 06/22/1992

Inventors: JOEL HENRION, MICHEL SCRIBAN, JEAN-BAPTISTE THIEBAUT, JEAN-FRANCOIS UHL

Title: INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHOMOGENEOUS STRUCTURE

Assignment: 1

Reel/Frame: 006370/0812 **Recorded:** 06/22/1992 **Pages:** 2

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST.

Assignors: HENRION, JOEL **Exec Dt:** 06/22/1992
SCRIBAN, MICHEL **Exec Dt:** 06/22/1992
THIEBAUT, JEAN-BAPTISTE **Exec Dt:** 06/22/1992
UHL, JEAN-FRANCOIS **Exec Dt:** 06/22/1992

Assignee: DIADIX S.A.
C/O AZAR S.A. 4 PLACE DE LA CONCORDE
75008 PARIS, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN
12400 WILSHIRE BOULEVARD
SEVENTH FLOOR
WEST LOS ANGELES, CA 90025
ATTN: ERIC S. HYMAN

Assignment: 2

Reel/Frame: 007785/0285 **Recorded:** 01/29/1996 **Pages:** 2

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

Assignor: DIADIX S.A. **Exec Dt:** 10/24/1995

Assignee: DEEMED INTERNATIONAL
2 AV. DE VIGNATE - CENTRE EQUATION, 38610
GIERES, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR ET AL.
ERIC S. HYMAN
12400 WILSHIRE BLVD.
SEVENTH FLOOR
LOS ANGELES, CA 90025

Assignment: 3

Reel/Frame: 009390/0742 **Recorded:** 08/17/1998 **Pages:** 5

Conveyance: CHANGE OF NAME (SEE DOCUMENT FOR DETAILS).

Assignor: DEEMED INTERNATIONAL **Exec Dt:** 08/14/1997

Assignee: ELEKTA IGS S.A.
2, AVENUE DE VIGNATE
BATIMENT 5 38610 GIERES, FRANCE

Correspondent: BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN
ERIC S. HYMAN
12400 WILSHIRE BOULEVARD
SEVENTH FLOOR

LOS ANGELES, CA 90025

Assignment: 4

Reel/Frame: 014384/0001 **Recorded:** 02/24/2003 **Pages:** 5

Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

Assignor: ELEKTA IGS S.A. **Exec Dt:** 12/14/1999

Assignee: MEDTRONIC, INC.
7000 CENTRAL AVENUE, N.E.
MINNEAPOLIS, MINNESOTA 55432

Correspondent: HARNESS, DICKEY & PIERCE, P.L.C.
STEPHEN J. FOSS
P.O. BOX 828
BLOOMFIELD HILLS, MI 48303

Search Results as of: 11/01/2011 09:19 AM
If you have any comments or questions concerning the data displayed, contact PRD / Assignments at 571-272-3350. v.2.2
Web interface last modified: July 25, 2011 v.2.2

LISTING OF CLAIMS

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;

means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;

means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;

means for determining a set of coordinates of the plurality of base points in the second reference frame;

means of intervention comprising an active member whose position is determined with respect to the second reference frame;

means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference

frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;

means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,

means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim 1, wherein the plurality of reference frame translation tools comprise:

means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;

means for creating a matrix (N) for transferring between the second reference frame and a second intermediate reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

{YP,YP, ZP}=M*N.sup.-1 *{XM,YM,ZM} where M * N.sup.-1 represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

{YM, YM, ZM}=N*M.sup.-1 *{XP,ZP,ZP} where N*M.sup.-1 represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

17. (Canceled)

18. (Canceled)

19. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention; and

a tracking system operable to determine a position of at least the second reference structure and a position of the active member and configured to transmit the determined positions of the second reference structure and the active member to the controller;

wherein the controller is configured to determine the position of the active member based on the determined position of at least the active member and the correlation of the first reference structure and the second reference structure.

20. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure includes a plurality of base points.

21. (previously presented) The interactive system as defined in Claim 20 wherein the second reference structure includes a plurality of tracking markers.

22. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure includes a plurality of tracking markers.

23. (previously presented) The interactive system as defined in Claim 22 wherein the plurality of tracking markers are attached to the patient.

24. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is attached to the patient.

25. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is attached to the patient.

26. (previously presented) The interactive system as defined in Claim 21 wherein the plurality of base points are generated from the plurality of tracking markers.

27. (previously presented) The interactive system as defined in Claim 20 wherein the plurality of base points are at least one of a plurality of notable points on the patient and marks fixed to the patient.

28. (previously presented) The interactive system as defined in Claim 27 wherein the notable points are selected from a group comprising a head, eyebrows, temples, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

29. (previously presented) The interactive system as defined in Claim 19 wherein the tracking system includes a marker device operable to determine a position of the second reference structure in relation to the patient reference frame.

30. (Amended) The interactive system as defined in Claim 29 wherein the marker device includes a telemetry system operable to determine the position of the second reference structure in the patient reference frame and transmit the determined position to the controller, wherein the controller is operable to perform the correlation at least with the transmitted determined position.

31. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an electromagnetic telemetry system.

32. (previously presented) The interactive system as defined in Claim 31 wherein the second reference structure includes electromagnetic tracking markers, wherein the electromagnetic telemetry system is operable to determine the position of the electromagnetic tracking markers of the second reference structure in relation to the patient reference frame.

33. (previously presented) The interactive system as defined in Claim 32, wherein the electromagnetic tracking markers are transmitters and the electromagnetic telemetry system is an electromagnetic sensor.

34. (previously presented) The interactive system as defined in Claim 30 wherein the telemetry system is an optical telemetry system.

35. (Amended) The interactive system as defined in Claim 34 wherein the optical telemetry system includes at least one of a video camera or an infrared camera to image at least the second reference structure and configured to plot points of the second reference structure.

36. (previously presented) The interactive system as defined in Claim 34 wherein the second reference structure includes optical tracking markers, wherein the optical telemetry system is operable to determine the position of the optical tracking markers of the second reference structure in relation to the patient reference frame.

37. (previously presented) The interactive system as defined in Claim 34 wherein the optical telemetry system utilizes position and shape recognition to identify the second reference structure.

38. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a three-dimensional probe.

39. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe includes a tactile tip operable to engage the second reference structure.

40. (previously presented) The interactive system as defined in Claim 38 wherein the three-dimensional probe is robotically manipulated, such that the instantaneous position of the three-dimensional probe is known.

41. (previously presented) The interactive system as defined in Claim 29 wherein the marker device includes a set of cameras operable to determine the position of the second reference structure in relation to the patient reference frame.

42. (previously presented) The interactive system as defined in Claim 41 wherein the set of cameras are selected from video and infrared cameras.

43. (previously presented) The interactive system as defined in Claim 29 wherein the marker device is a laser beam emission system operable to illuminate the second reference structure to determine a position of the second reference structure in relation to the patient reference frame.

44. (previously presented) The interactive system as defined in Claim 20 wherein the controller further includes a graphical tool operable to identify the plurality of

base points of the first reference structure in the image data of the image data reference frame.

45. (previously presented) The interactive system as defined in Claim 44 wherein the graphical tool is a mouse in communication with the controller.

46. (previously presented) The interactive system as defined in Claim 19 wherein the first reference structure is generated from the second reference structure.

47. (canceled)

48. (Amended) The interactive system as defined in Claim 19 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

49. (Amended) The interactive system as defined in Claim 19 further comprising a telemetry system operable to determine the position of the active member in the patient reference frame, said telemetry system in communication with the controller.

50. (previously presented) The interactive system as defined in Claim 49 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

51. (Amended) The interactive system as defined in Claim [[47]] 19 wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame.

52. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

53. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to model a reference origin of intervention and a direction of intervention and said display is further operable to display the modeled reference origin of intervention and direction of intervention.

54. (Amended) The interactive system as defined in Claim 51 wherein the display is further operable to display the real-time position of the active member in the image reference frame based on the determined position of the active member with the tracking system.

55. (previously presented) The interactive system as defined in Claim 51 wherein the display is further operable to display image data relative to a direction of intervention of the active member.

56. (previously presented) The interactive system as defined in Claim 55 wherein the image data is displayed perpendicular to a direction of intervention of the active member.

57. (previously presented) The interactive system as defined in Claim 51 wherein the controller is further operable to simulate an optimal trajectory of advance of the active member and said display is operable to display the optimal trajectory in the image data relative to the image reference frame.

58. (previously presented) The interactive system as defined in Claim 57 wherein movement of the active member is steered to the optimal trajectory to carry out a programmed intervention.

59. (Amended) The interactive system as defined in Claim 19 wherein the active member is robotically controlled.

60. (previously presented) The interactive system as defined in Claim 19 wherein the image data is at least one of a magnetic resonance image data, a

tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

61. (previously presented) The interactive system as defined in Claim 19 wherein the device is operable to construct three-dimensional images from captured two-dimensional images.

62. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient; and

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

wherein the device is operable to construct three-dimensional images from captured two-dimensional images;

wherein the controller is operable to superimpose two-dimensional image data on the three-dimensional images wherein any change in soft external parts of the patient can be visualized as compared with the image captured by the imaging device.

63. (previously presented) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame; and

an active member operable to perform the intervention;

wherein the device includes a display operable to display the image data of the region of the patient in relation to the image reference frame;

wherein the controller is further operable to determine residual uncertainty which is used to represent a contour with dimensions larger than those which would normally be represented and the display is operable to display the residual uncertainty of the contour.

64. (previously presented) The interactive system as defined in Claim 63 wherein the contour is a display of an active member and a representation of residual uncertainty in order to reduce the chance of traversing undesired structures.

65. (previously presented) The interactive system as defined in Claim 19 wherein the controller is further operable to correlate map data in a map reference frame with the patient reference frame.

66. (Amended) The interactive system as defined in Claim 19 wherein the intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

67. (previously presented) The interactive system as defined in Claim 19 wherein the second reference structure is fixed to a head set.

68. (previously presented) The interactive system as defined in Claim 60 wherein the head set is further fixed to an operating table.

69. (previously presented) The interactive system as defined in Claim 19 wherein the device further includes memory operable to store the image data.

70. (previously presented) The interactive system as defined in Claim 19 wherein the device is a first computer.

71. (previously presented) The interactive system as defined in Claim 70 wherein the controller is a second computer.

72. (previously presented) The interactive system as defined in Claim 71 wherein the first computer and the second computer is a single work station.

73. (Twice Amended) An interactive system for intervention inside a region of a patient, said interactive system comprising:

a device operable to receive image data of the region of the patient, wherein the image data includes image data of a first reference structure to establish an image reference frame for the region of the patient;

a second reference structure positioned relative to the patient to establish a patient reference frame for the region of the patient;

a controller operable to correlate the position of the first reference structure in the image reference frame with the position of the second reference structure in the patient reference frame;

an active member operable to perform the intervention inside the region of the patient;

a tracking system operable to track the position of the active member in relation to the patient reference frame, the tracking system being in communication with the controller to transmit the tracked position of the active member as position information to the controller, wherein the controller is operable to determine the position of the active member relative to the image reference frame; and

a display operable to display the real-time position of the active member in the image reference frame based on the controller determined position of the active member based on the tracked position of the active member from the tracking system, wherein the controller is configured to generate a representation of the active member that is displayed on the display relative to a display of the received image data.

74. (previously presented) The interactive system as defined in Claim 73 wherein the active member is selected from a group comprising a trephining tool, a needle, a laser, a radioscope emission head, an endoscopic viewing system, a tool used in the intervention, an implant, a sighting system, a microscope, and combinations thereof.

75. (previously presented) The interactive system as defined in Claim 73 wherein the position information of the active member is six degree of freedom information in relation to the patient reference frame.

76. (previously presented) The interactive system as defined in Claim 73 wherein the tracking system that tracks the position of the active member is a telemetry system in communication with the controller.

77. (previously presented) The interactive system as defined in Claim 73 wherein the active member is robotically controlled.

78. (previously presented) The interactive system as defined in Claim 73 wherein the image data is at least one of a magnetic resonance image data, a tomographic image data, a radiographic image data, x-ray image data, and combinations thereof.

79. (previously presented) The interactive system as defined in Claim 73 wherein the controller is further operable to determine a reference origin of intervention and a direction of intervention and said display is further operable to display the reference origin of intervention and direction of intervention.

80. (previously presented) The interactive system as defined in Claim 73 wherein the first reference structure includes a plurality of base points.

81. (previously presented) The interactive system as defined in Claim 80 wherein the second reference structure includes a plurality of tracking markers.

82. (previously presented) The interactive system as defined in Claim 81 wherein the plurality of base points are generated by the plurality of tracking markers.

83. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is attached to the patient.

84. (previously presented) The interactive system as defined in Claim 73 wherein intervention is at least one of a neurosurgery, orthopedic surgery, cranial surgery intervention, and combinations thereof.

85. (previously presented) The interactive system as defined in Claim 73 wherein the second reference structure is fixed to a head set.

86. (Amended) The interactive system as defined in Claim 73 wherein the display forms part of the device and wherein the image data received is acquired image data of the region of the patient and is displayed on the display, further wherein the representation of the active member is displayed on the acquired image data of the region of the patient.

87. (Twice Amended) A method for performing an image guided intervention inside a region of a patient, said method comprising:

accessing a first image data of the region of the patient captured with an imaging system where the first image data includes image data of a first reference structure;

identifying the first reference structure in the first image data to establish an image reference frame;

identifying a second reference structure relative to the patient to establish a patient reference frame;

correlating the position of the first reference structure in the image reference frame in the first image data with the position of the second reference structure in the patient reference frame; and

tracking an active member at least to determine a position of the active member in the patient reference frame to determine a location of the active member based on the tracking of the active member and transmitting the determined position in the patient refrence frame for display on a display device relative to the image reference frame of the first image data based at least on the correlation of the first reference structure and the second reference structure.

88. (previously presented) The method as defined in Claim 87 further comprising attaching a plurality of tracking markers to the patient where the tracking markers form the second reference structure.

89. (previously presented) The method as defined in Claim 88 further comprising identifying the position of the tracking markers in the patient reference frame using a telemetry system.

90. (Amended) The method as defined in Claim 89 further comprising transmitting from the tracking markers a signal and receiving the transmitted signal with an electromagnetic sensor to identify the position of the second reference structure in the patient reference frame.

91. (previously presented) The method as defined in Claim 87 wherein identifying the first reference structure includes identifying a plurality of base points visible in the image data.

92. (previously presented) The method as defined in Claim 91 wherein identifying the plurality of base points includes identifying at least one of notable points on the patient as marks fixed to the patient representing the plurality of base points.

93. (previously presented) The method as defined in Claim 92 wherein the notable points are selected from a group comprising a head, eyebrows, temporal point, frontal medial point, an apex of a skull, a center of gravity of an orbits of the eyes and a combination thereof.

94. (previously presented) The method as defined in Claim 91 wherein the plurality of base points visible in the image data are generated from the plurality of tracking markers attached to the patient.

95. (previously presented) The method as defined in Claim 87 further comprising attaching the second reference structure to the patient.

96. (previously presented) The method as defined in Claim 87 further comprising displaying the image data of the region of the patient, including displaying the first reference structure.

97. (previously presented) The method as defined in Claim 87 further comprising performing an intervention on the patient with an active member.

98. (Canceled)

99. (Amended) The method as defined in Claim 96 further comprising:

displaying the position of the active member as a representation of the active member in the accessed first image data that is captured image data that is correlated to the patient based on the correlation and displayed on a display device with the position of the active member being correlated between the patient reference frame defined by the first reference structure fixed to the patient and the image reference frame based on the tracking of the active member.

100. (Amended) The method as defined in Claim 99 further comprising identifying the position of the active member with a telemetry system by transmitting the tracked location of the active member for displaying the representation of the active member.

101. (previously presented) The method as defined in Claim 99 further comprising displaying a reference origin of intervention and a direction of intervention in the image data.

102. (previously presented) The method as defined in Claim 101 further comprising tracking the position of the active member relative to the reference origin of intervention and the direction of intervention.

103. (previously presented) The method as defined in Claim 87 further comprising converting two-dimensional image data to three-dimensional image data.

104. (previously presented) The method as defined in Claim 97 wherein the intervention is selected from at least one of a neurosurgery, orthopedic surgery, cranial surgery, and combinations thereof.

105. (previously presented) The method as defined in Claim 95 further comprising attaching the second reference structure to a head set.

US005868675A

United States Patent [19]

Henrion et al.

[11] **Patent Number: 5,868,675**

[45] **Date of Patent: *Feb. 9, 1999**

[54] **INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE**

[75] Inventors: **Joël Henrion**, Suippes; **Michel Scriban**, Ternay; **Jean-Baptiste Thiebaut**; **Jean-François Uhl**, both of Paris, all of France

[73] Assignee: **Elekta IGS S.A.**, Gieres, France

[*] Notice: The terminal 36 months of this patent has been disclaimed.

[21] Appl. No.: **847,059**

[22] PCT Filed: **May 10, 1990**

[86] PCT No.: **PCT/FR90/00714**

§ 371 Date: **Jun. 22, 1992**

§ 102(e) Date: **Jun. 22, 1992**

[87] PCT Pub. No.: **WO91/04710**

PCT Pub. Date: **Apr. 18, 1991**

[30] **Foreign Application Priority Data**

Oct. 5, 1989 [FR] France 89 13028

[51] **Int. Cl.**^{6} **A61B 5/05**

[52] **U.S. Cl.** **600/424**; 606/130

[58] **Field of Search** 128/653.1; 378/4, 378/20, 41, 58, 205; 606/130; 901/6, 16, 41; 600/407, 411, 415, 417, 424

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,638,798	1/1987	Shelden et al.	606/130
4,791,934	12/1988	Brunnett	128/653.1
5,050,608	9/1991	Watanabe et al.	128/653.1
5,078,140	1/1992	Kwoh	128/653.1
5,143,076	9/1992	Hardy et al.	606/130
5,186,174	2/1993	Schlöndorff et al.	128/653.1
5,273,039	12/1993	Fujiwara et al.	600/407
5,280,427	1/1994	Magnusson et al.	606/130
5,285,787	2/1994	Machida	606/130
5,409,497	4/1995	Siczek et al.	606/130
5,572,999	11/1996	Fubda et al.	600/407

FOREIGN PATENT DOCUMENTS

0009151	12/1988	WIPO .
WO 88/09151	12/1988	WIPO .

OTHER PUBLICATIONS

Lavallee, S. A New System for Computer Assisted Neurosurgery. IEEE Engineering in Medicine & Biology Society 11th Annual International Conference, vol. 11, pp. 926–927, Nov. 1989.

Watanabe, E et al. Three-Dimenstional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotaxic Surgery. Surg. Neurol., vol. 27, pp. 543–547, 1987.

(List continued on next page.)

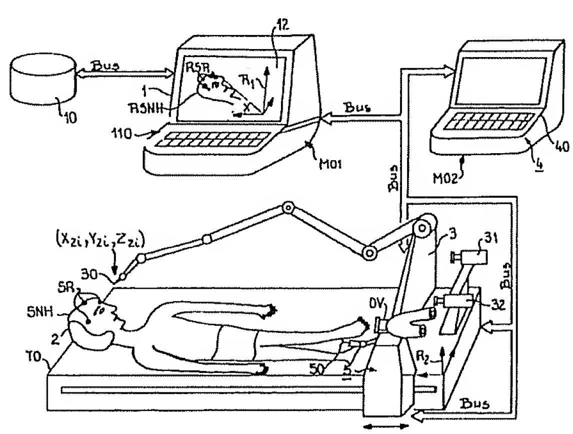
Primary Examiner—Brian Casler

Attorney, Agent, or Firm—Blakely Sokoloff Taylor & Zafman

[57] **ABSTRACT**

An interactive system for a local intervention inside a region of a non-homogeneous structure, such as the skull of a patient, which is related to the frame of reference (R_2) of an operation table, and which is connected to a reference structure comprising a plurality of base points. The system creates on a screen a representation of the non-homogeneous structure and of the reference structure connected thereto, provides the coordinates of the images of the base points in the first frame of reference (R_1), allows the marking of the coordinates of the base points in R_2, and allows the carrying out of the local intervention with an active member such as a trephining tool, a needle, or a radioactive or chemical implant. The systems also optimizes the transfer of reference frames between R_1 and R_2, from the coordinates of the base points in R_2 and the images in R_1 by reducing down to a minimum the deviations between the coordinates of images in R_1 and the base points in R_1 after transfer. The system also establishes real time bi-directional coupling between: (1) an origin and a direction of intervention simulated on the screen, (2) the position of the active member.

16 Claims, 13 Drawing Sheets



OTHER PUBLICATIONS

Batnitzky, S. et al. Three–Dimensional Computer Reconstruction from Surface Contours for Head CT Examinations. J. Comp. Asst. Tomogr., vol. 5, No. 1, pp. 60–67, Feb. 1981.

Roberts, D.W., et al. A Frameless Stereotaxic Integration of Computerized Tomographic Imaging and the Operating Microscope. J. Neurosurg., vol. 65, pp. 545–549, 1986.

Kelly, P.J. et al. Computer–assisted Stereotactic Laser Microsurgery for the Treatment of Intracranial Neoplasms, Neurosurgery. vol. 10, No. 3, pp. 324–330, 1982.

S. Lavallee, "A New System for Computer Neurosurgery", IEEE Eng. in Medicine & Bio. Soc. 11th Annual Int. Conf., Nov. 9–12, 1989, pp. 926–927.

Watanabe et al., Three Dimensional Digitizer (Neuronavigator): New Equipment for Computed Tomography–Guided Stereotoxic Surgery, Surg. Neurol., 1987, No. 27, pp. 543–547.

P.J. Kelly et al., "Computer–Assisted Stereotactic Laser Micro–Surgery for the Treatment of Intracranial Neoplasms", Neuro., vol. 10, No. 3, 1982, pp. 324–330.

Batnitzky et al., "Three–dimensional Computer Reconstruction From Surface Contours for Head CT Examinations", Journal of Comp. Assisted Tomography, No. 5, Feb. 1981, pp. 60–67

Roberts et al., "A Frameless Stereotoxic Integration of Computerized Tomographic Imaging and the Operating Microsc gsl", J. of Neuro. Surg. No. 65, 1986, pp. 545–549.

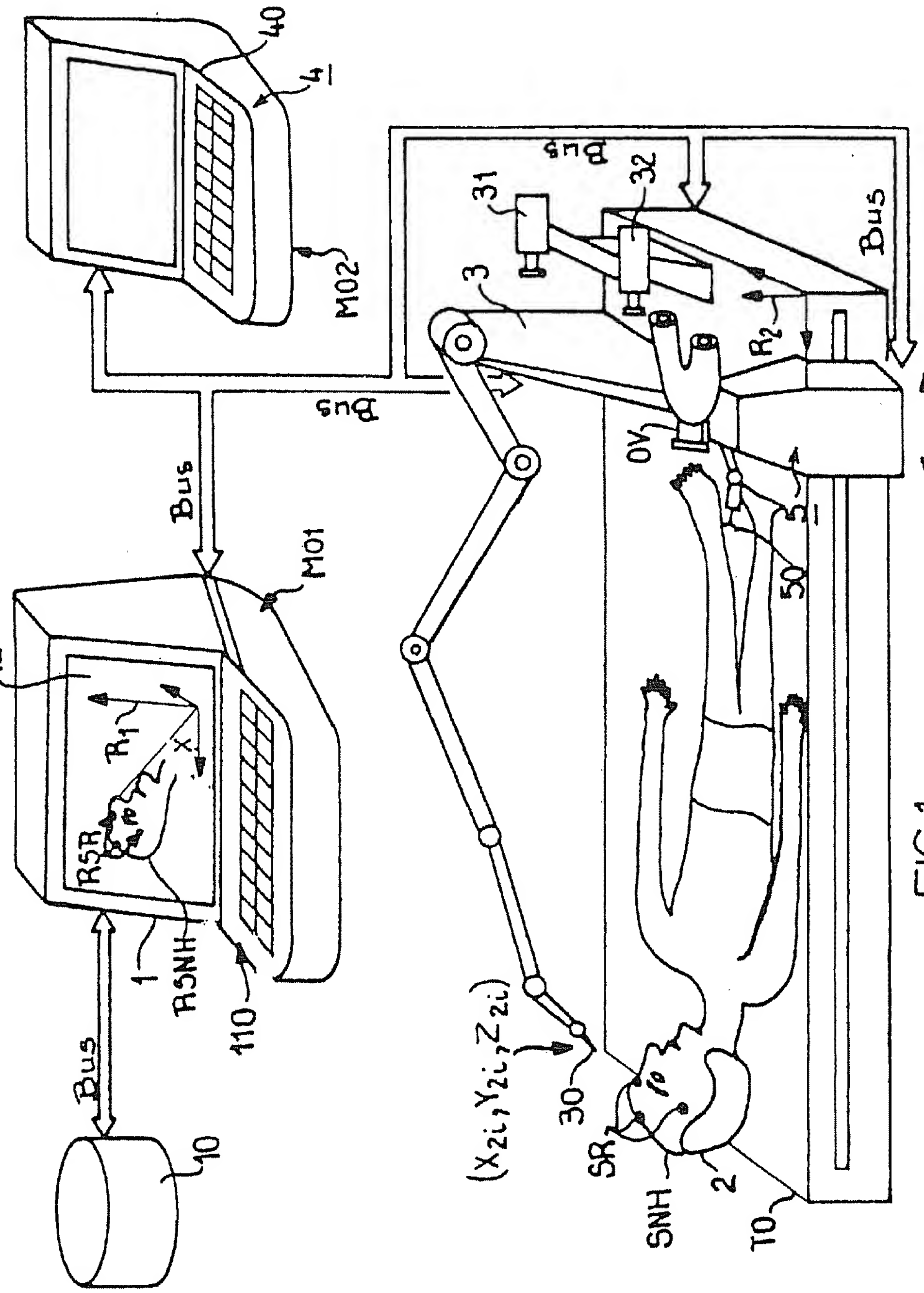

40
4
M02
Bus
31
32
3
Bus
R2
OV
5
50
Bus
M01
12
R1
RSR
RSNH
1
110
Bus
10
(X_{2i}, Y_{2i}, Z_{2i})
30
SR
SNH
2
TO

FIG.1

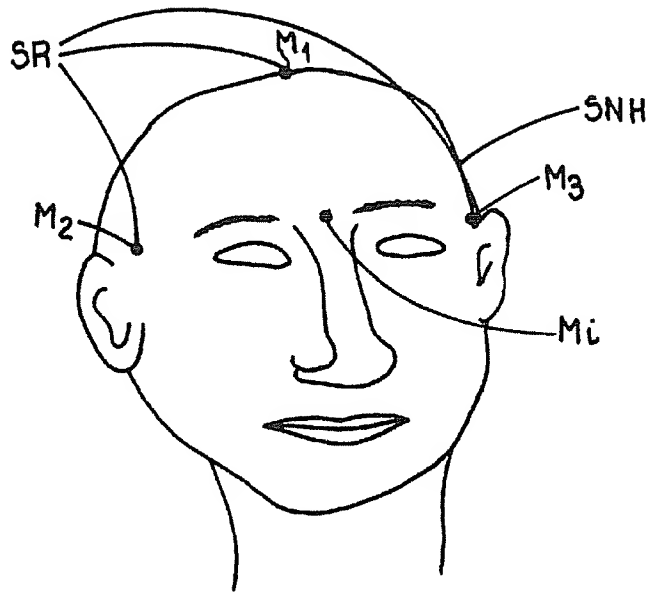


FIG_2

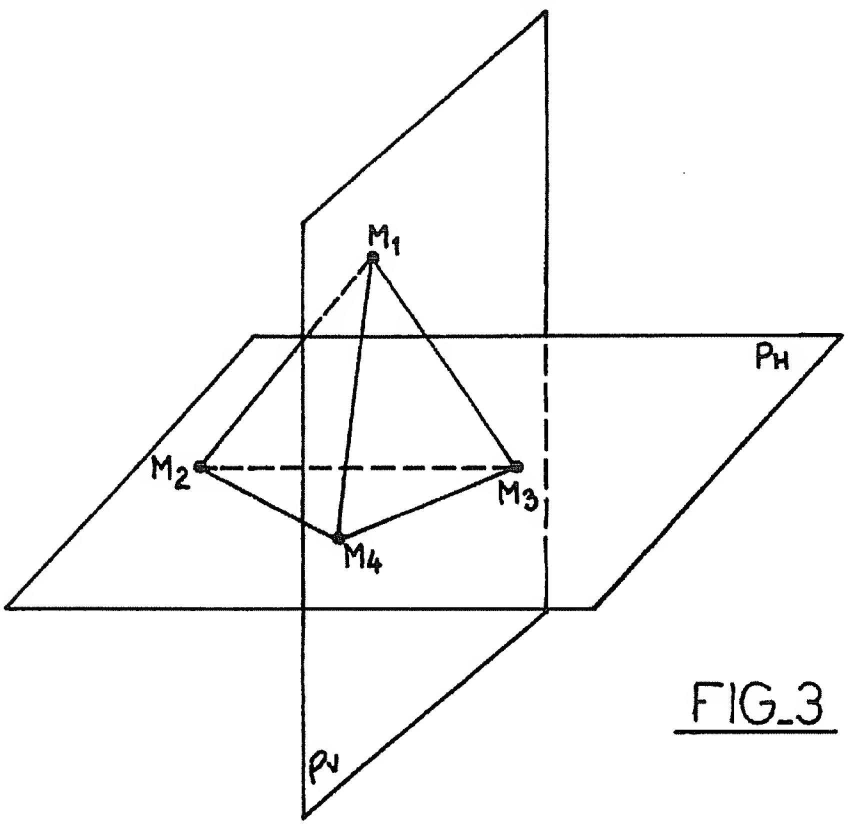


FIG_3

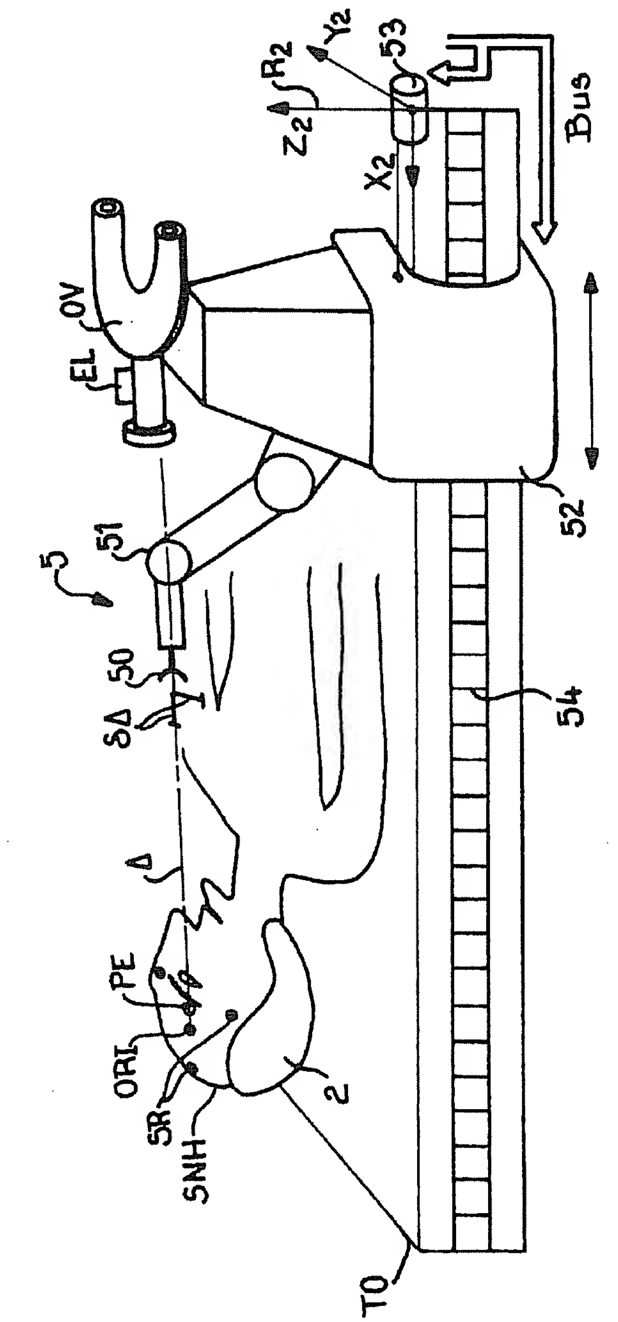


FIG_4

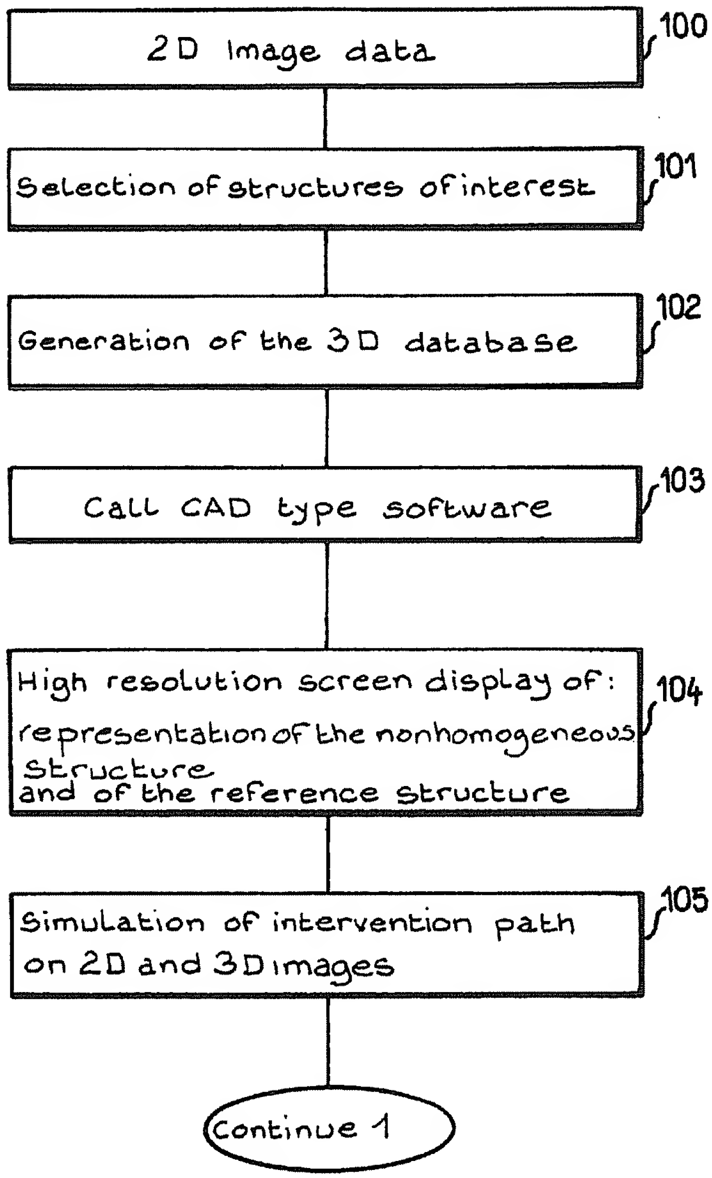

2D Image data
100
Selection of structures of interest
101
Generation of the 3D database
102
Call CAD type software
103
High resolution screen display of:
representation of the nonhomogeneous structure
and of the reference structure
104
Simulation of intervention path
on 2D and 3D images
105
Continue 1

FIG_5a

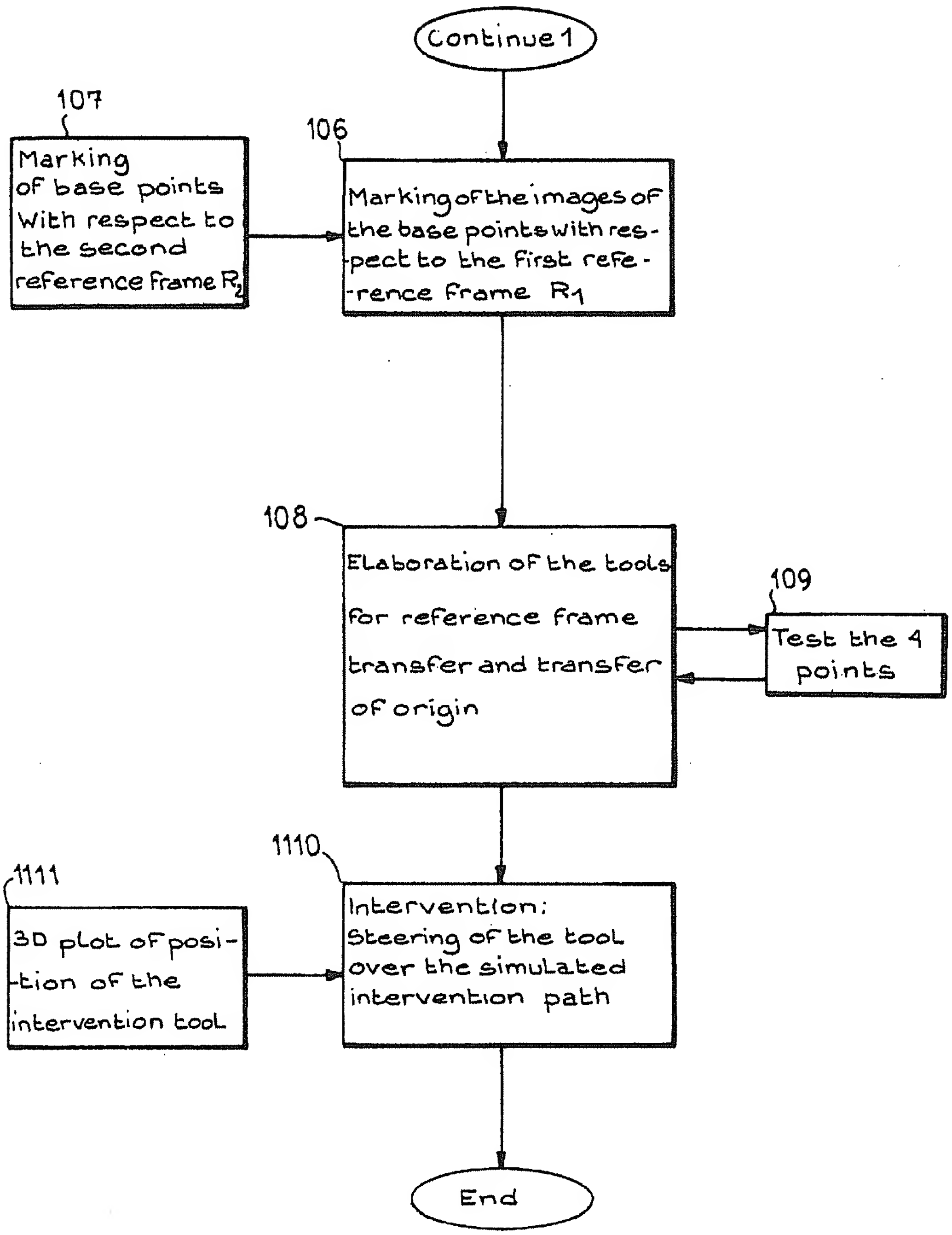

Continue 1
107
Marking of base points With respect to the second reference frame R_2
106
Marking of the images of the base points with respect to the first reference frame R_1
108
Elaboration of the tools for reference frame transfer and transfer of origin
109
Test the 4 points
1110
1111
3D plot of position of the intervention tool
Intervention: Steering of the tool over the simulated intervention path
End

FIG_5b

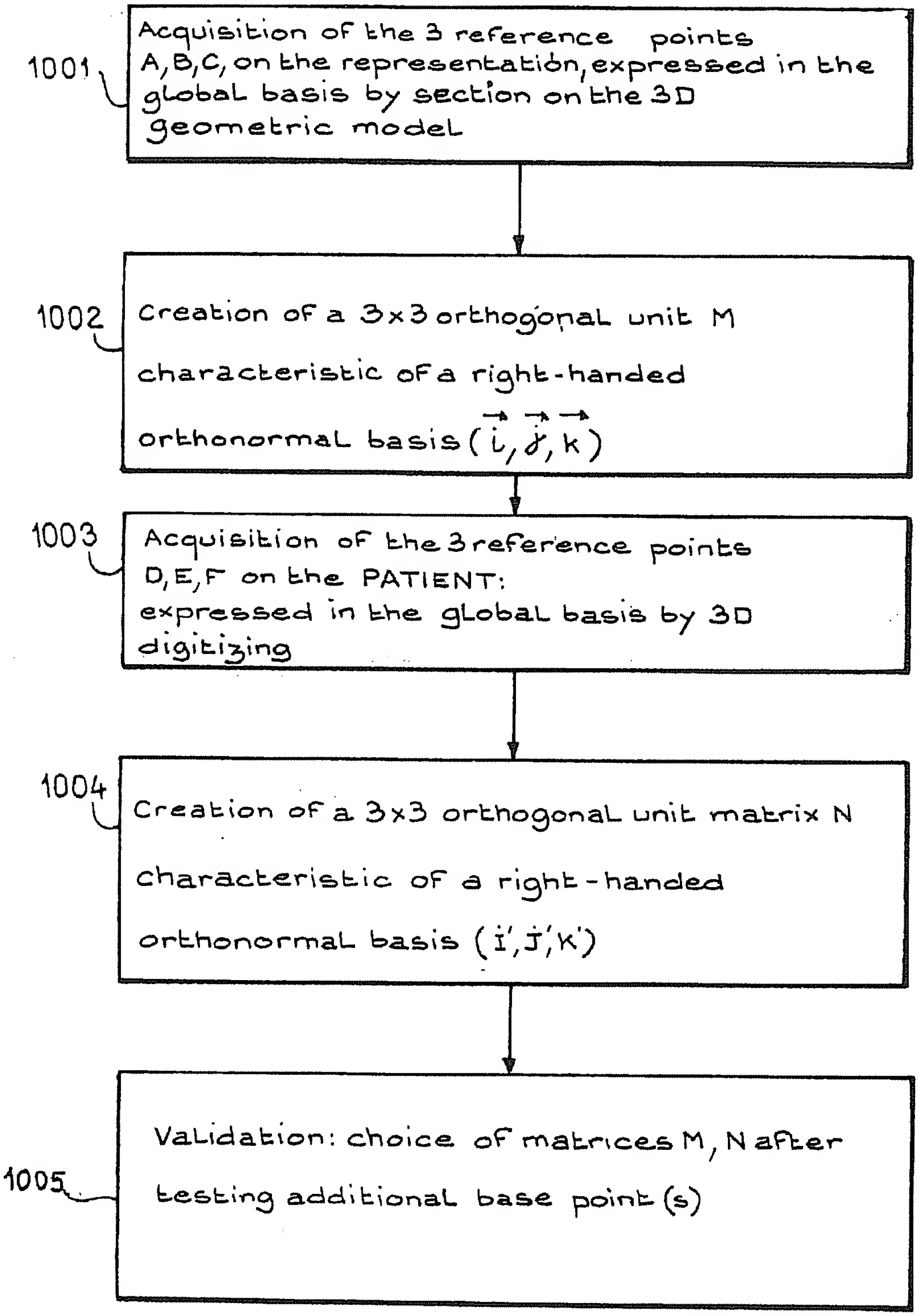

1001
Acquisition of the 3 reference points A, B, C, on the representation, expressed in the global basis by section on the 3D geometric model
1002
Creation of a 3x3 orthogonal unit M characteristic of a right-handed orthonormal basis ($\vec{i}, \vec{j}, \vec{k}$)
1003
Acquisition of the 3 reference points D, E, F on the PATIENT: expressed in the global basis by 3D digitizing
1004
Creation of a 3x3 orthogonal unit matrix N characteristic of a right-handed orthonormal basis (i', j', k')
1005
Validation: choice of matrices M, N after testing additional base point (s)

FIG 6

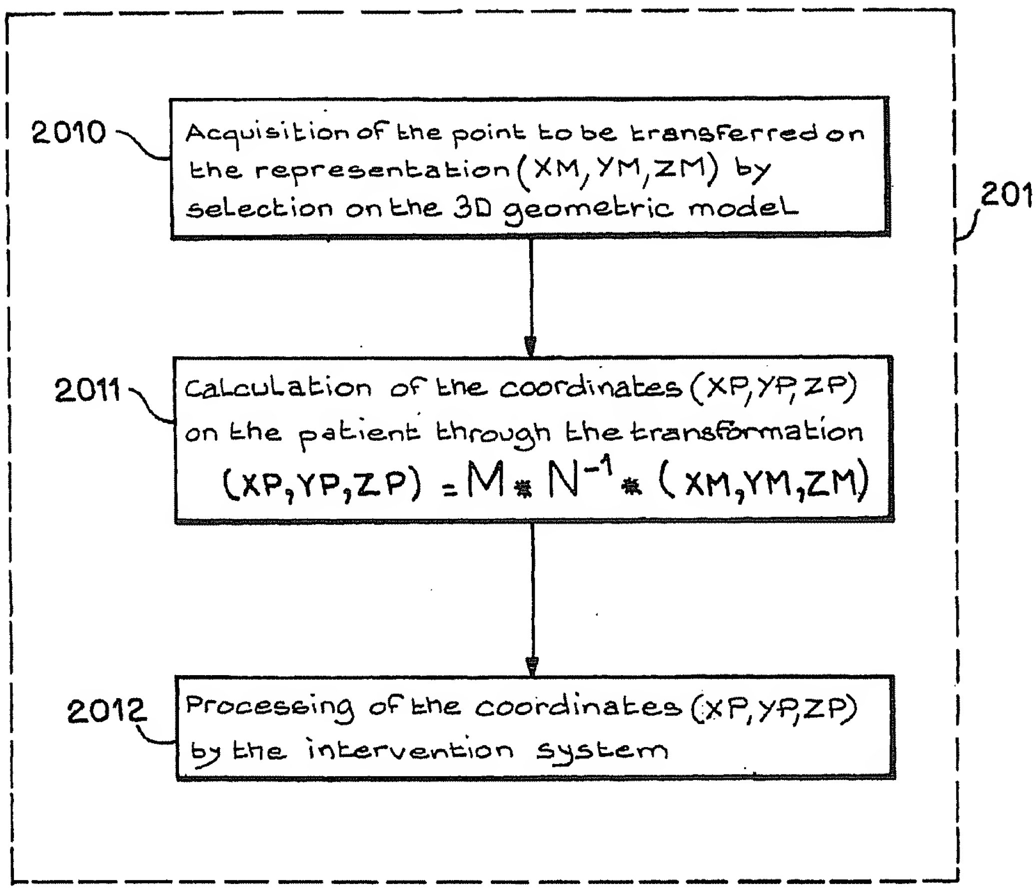

2010
Acquisition of the point to be transferred on the representation (XM, YM, ZM) by selection on the 3D geometric model
201
2011
Calculation of the coordinates (XP, YP, ZP) on the patient through the transformation
(XP, YP, ZP) = M * N-1 * (XM, YM, ZM)
2012
Processing of the coordinates (XP, YP, ZP) by the intervention system

FIG_7

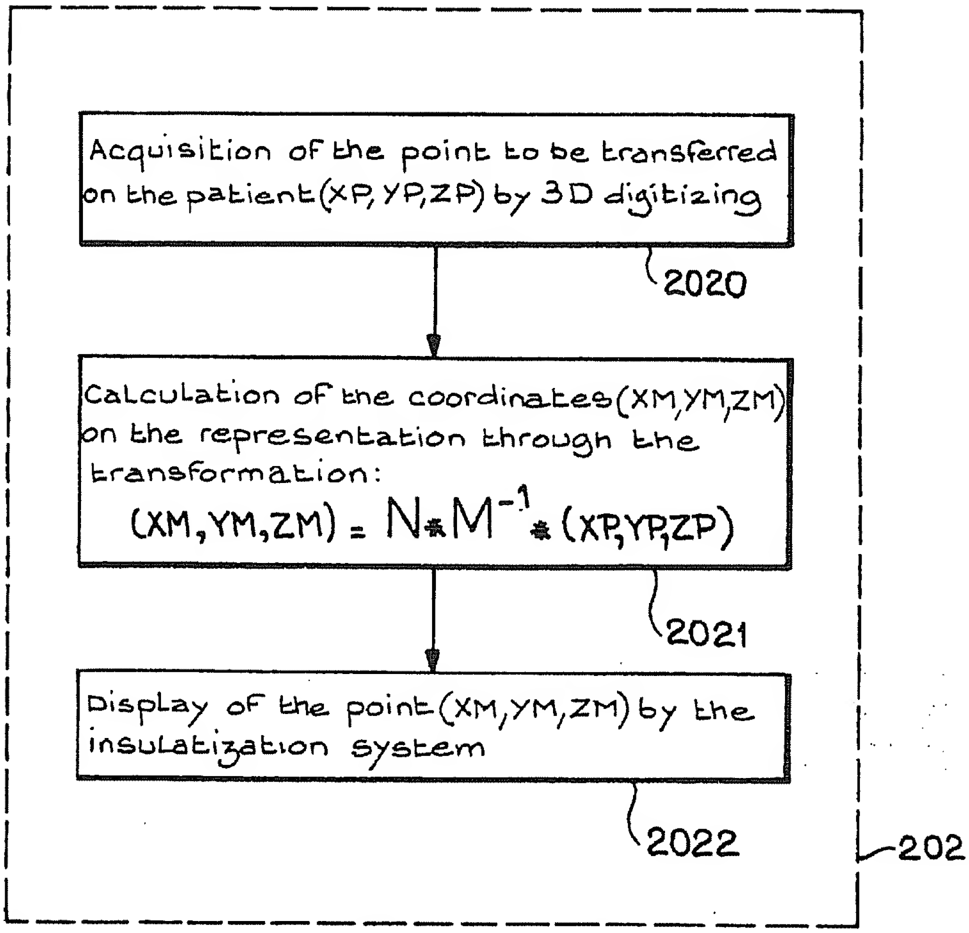

Acquisition of the point to be transferred on the patient (XP, YP, ZP) by 3D digitizing
2020
Calculation of the coordinates (XM, YM, ZM) on the representation through the transformation:
(XM, YM, ZM) = N * M^-1 * (XP, YP, ZP)
2021
Display of the point (XM, YM, ZM) by the insulatization system
2022
202

FIG_8

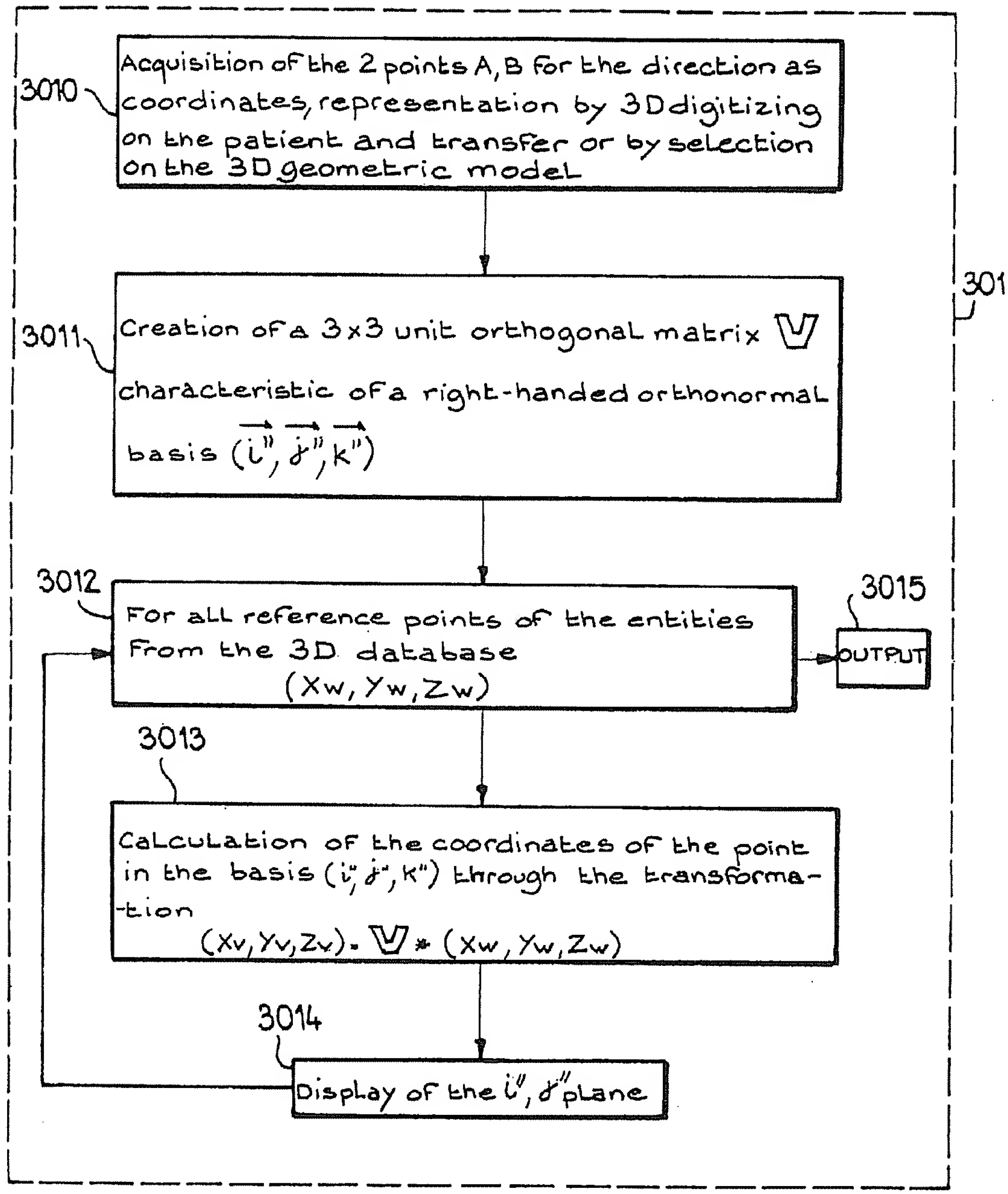

3010
Acquisition of the 2 points A, B for the direction as coordinates, representation by 3D digitizing on the patient and transfer or by selection on the 3D geometric model
3011
Creation of a 3x3 unit orthogonal matrix V characteristic of a right-handed orthonormal basis ($\vec{i}''$, $\vec{j}''$, $\vec{k}''$)
301
3012
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3015
OUTPUT
3013
Calculation of the coordinates of the point in the basis (i", j", k") through the transformation (Xv, Yv, Zv) = V * (Xw, Yw, Zw)
3014
Display of the i", j" plane

FIG. 9a

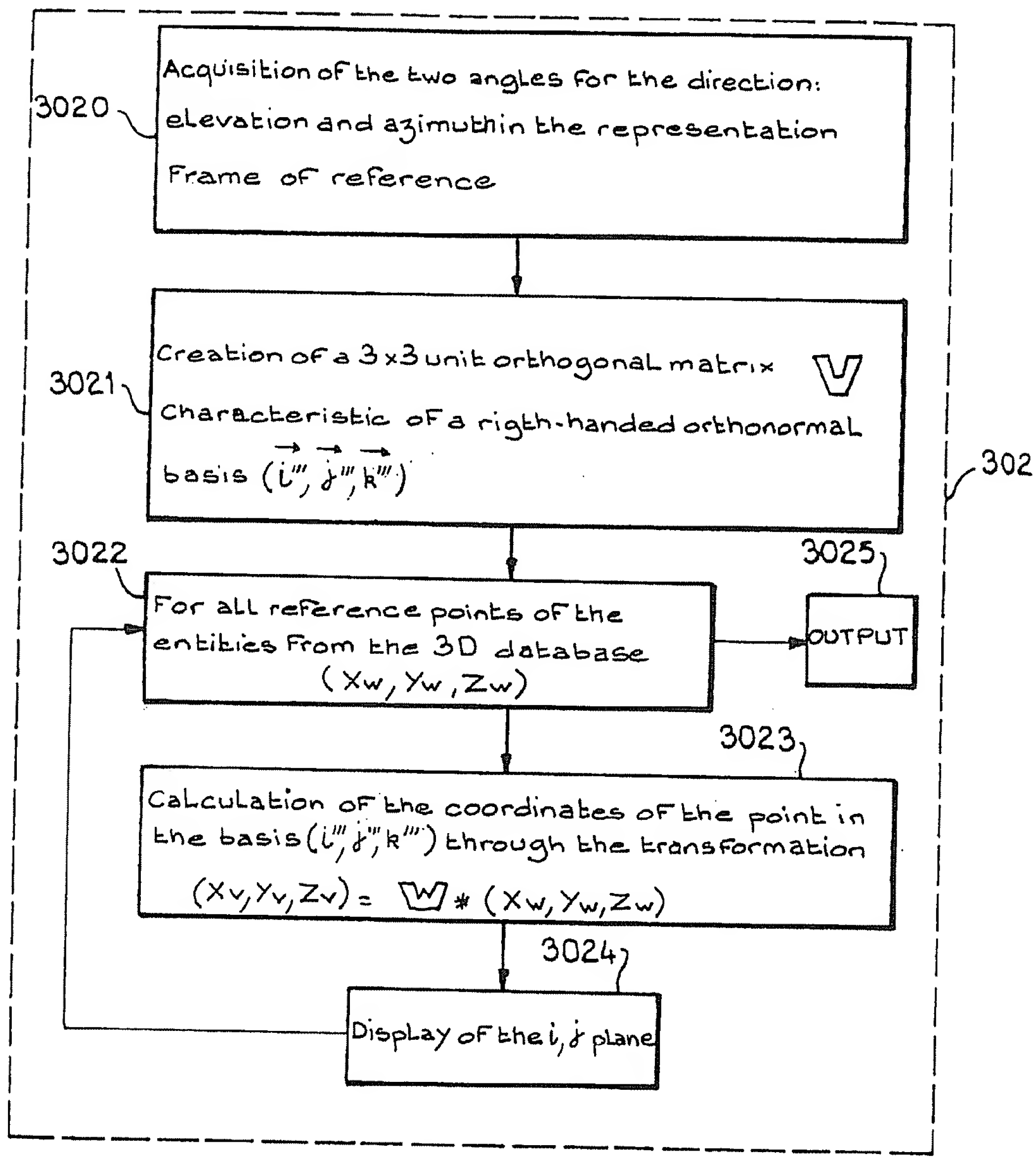

3020
Acquisition of the two angles for the direction: elevation and azimuth in the representation frame of reference
3021
Creation of a 3x3 unit orthogonal matrix V characteristic of a rigth-handed orthonormal basis ($\vec{i}'''$, $\vec{j}'''$, $\vec{k}'''$)
302
3022
For all reference points of the entities from the 3D database (Xw, Yw, Zw)
3025
OUTPUT
3023
Calculation of the coordinates of the point in the basis (i''', j''', k''') through the transformation
(Xv, Yv, Zv) = W * (Xw, Yw, Zw)
3024
Display of the i, j plane

FIG_9b

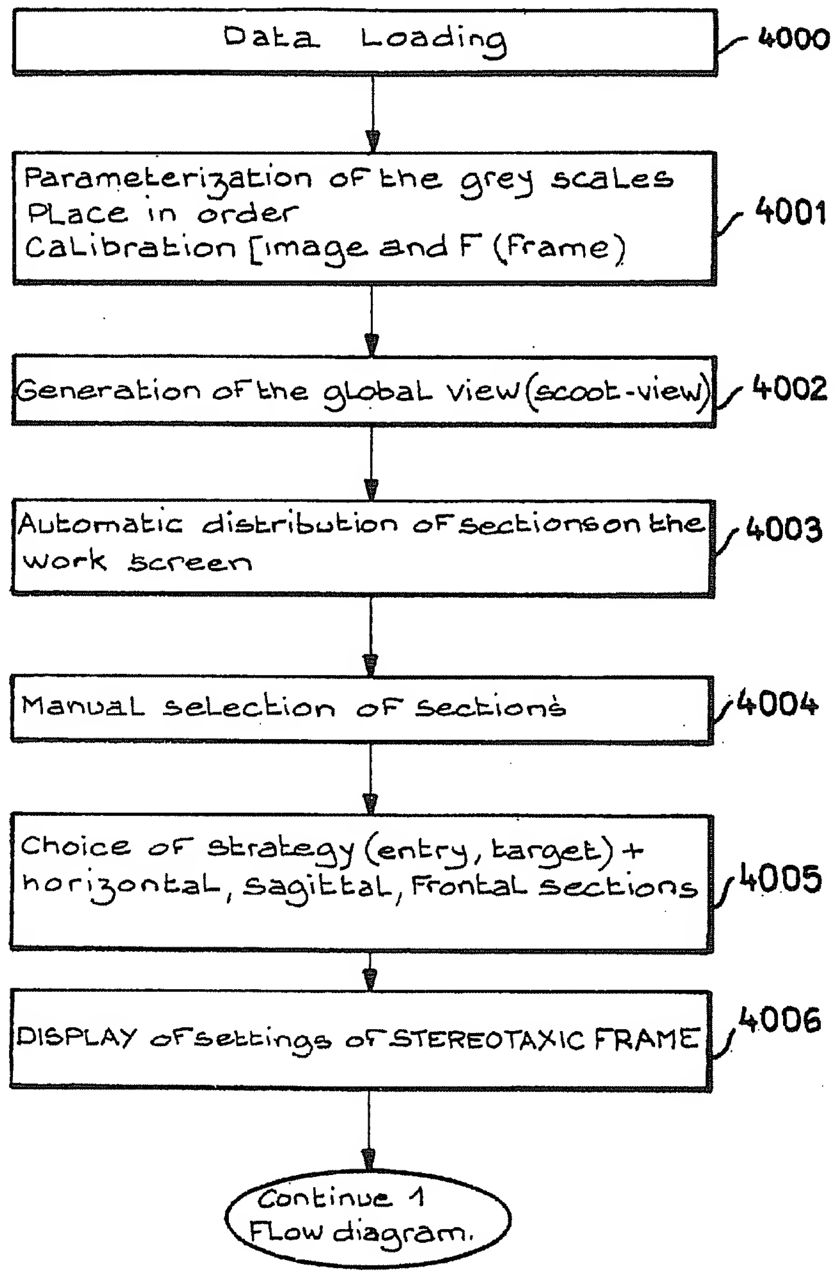

Data Loading
4000
Parameterization of the grey scales
Place in order
Calibration [image and F (frame)
4001
Generation of the global view (scoot-view)
4002
Automatic distribution of sections on the work screen
4003
Manual selection of sections
4004
Choice of strategy (entry, target) + horizontal, sagittal, Frontal sections
4005
DISPLAY of settings of STEREOTAXIC FRAME
4006
Continue 1
Flow diagram.

FIG_10a

FIG_10b

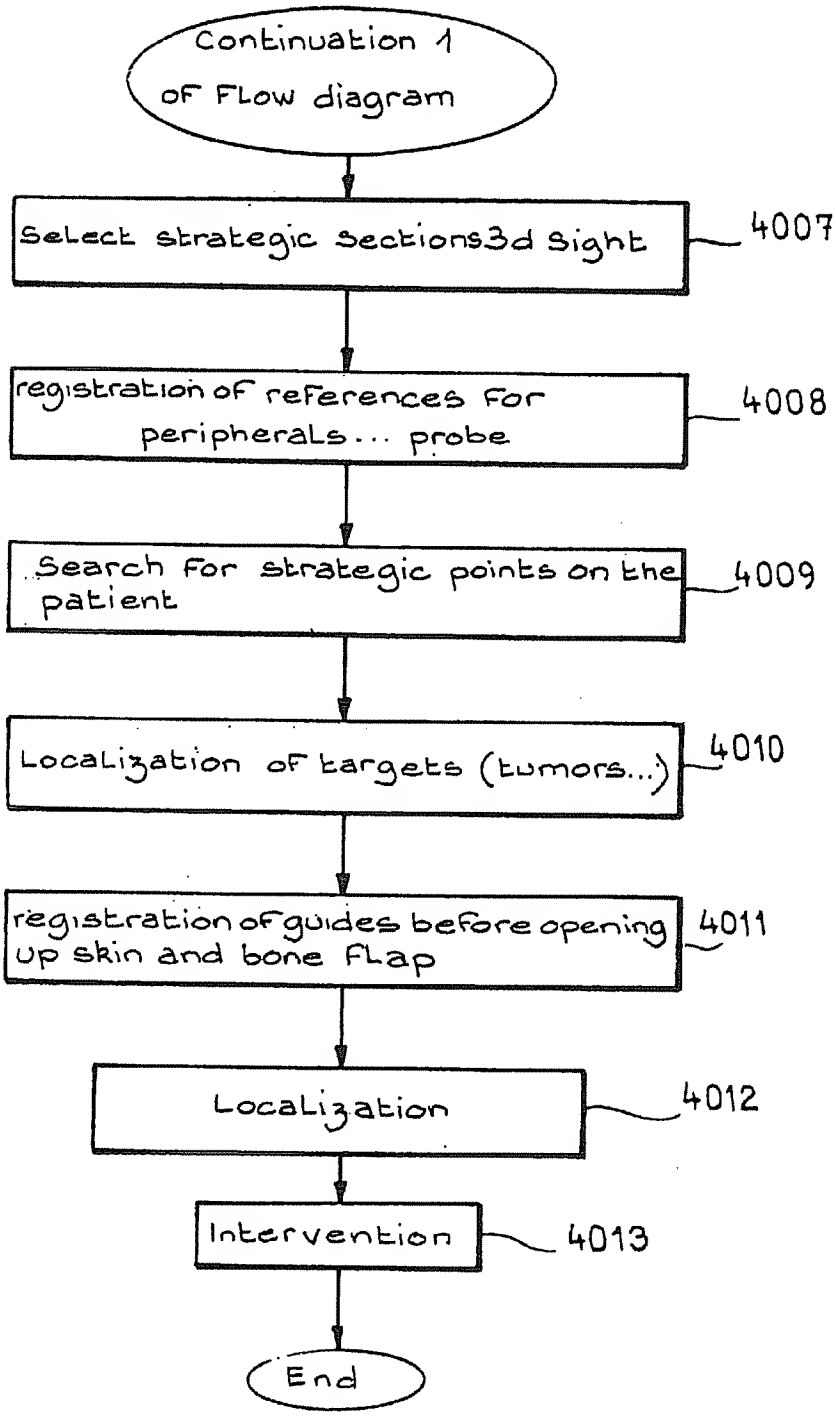
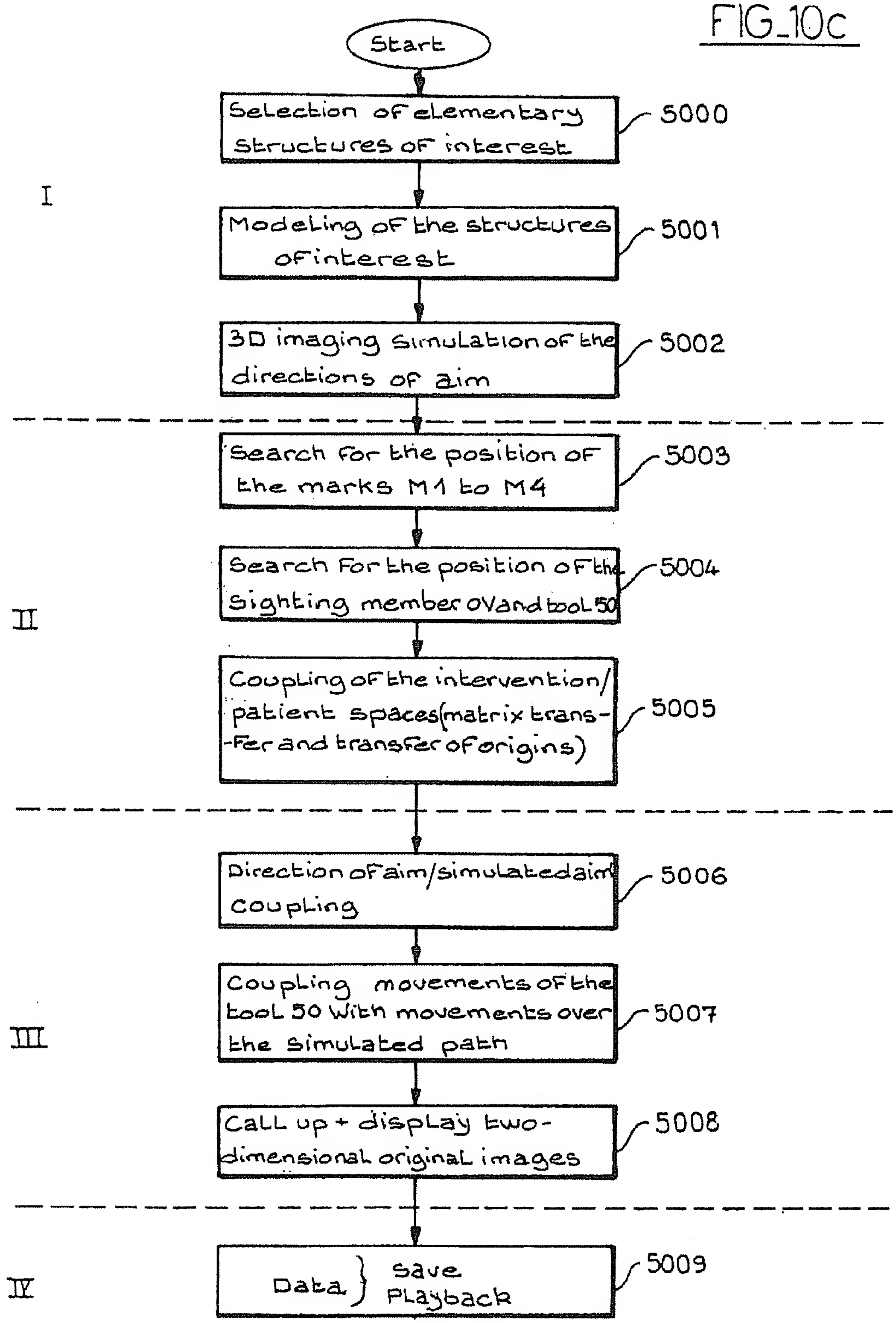

Continuation 1
of Flow diagram
Select strategic sections3d sight
4007
registration of references for peripherals... probe
4008
Search for strategic points on the patient
4009
Localization of targets (tumors...)
4010
registration of guides before opening up skin and bone flap
4011
Localization
4012
Intervention
4013
End

FIG_10c


Start
Selection of elementary structures of interest
5000
I
Modeling of the structures of interest
5001
3D imaging simulation of the directions of aim
5002
Search for the position of the marks M1 to M4
5003
Search for the position of the sighting member OV and tool 50
5004
II
Coupling of the intervention/patient spaces (matrix trans--fer and transfer of origins)
5005
Direction of aim/simulated aim coupling
5006
Coupling movements of the tool 50 with movements over the simulated path
5007
III
Call up + display two-dimensional original images
5008
Data } Save Playback
5009
IV

INTERACTIVE SYSTEM FOR LOCAL INTERVENTION INSIDE A NONHUMOGENEOUS STRUCTURE

The invention relates to an interactive system for local intervention inside a region of a nonhomogeneous structure.

The performing of local interventions inside a nonhomogeneous structure, such as intracranial surgical operations or orthopedic surgery currently poses the problem of optimizing the intervention path or paths so as to secure, on the one hand, total intervention over the region or structure of interest, such as a tumor to be treated or explored and, on the other hand, minimal lesion to the regions neighboring or adjoining the region of interest, this entailing the localizing and then the selecting of the regions of the nonhomogeneous structure which are least sensitive to being traversed or the least susceptible to damage as regards the integrity of the structure.

Numerous works aimed at providing a solution to the abovementioned problem have hitherto been the subject of publications. Among the latter may be cited the article entitled "Three Dimensional Digitizer (Neuronavigator): New Equipment for computed Tomography Guided Stereotaxic Surgery", published by Eiju Watanabe, M.D., Takashi Watanabe, M.D., Shinya Manaka, M.D., Yoshiaki Mayanagi, M.D., and Kintomo Takakura, M.D. Department of Neurosurgery, Faculty of Medicine, University of Tokyo, Japan, in the journal Surgery Neurol. 1987: 27 pp. 543–547, by Elsevier Science Publishing Co., Inc. The Patent WO-A-88 09151 teaches a similar item of equipment.

In the abovementioned publications are described in particular a system and an operational mode on the basis of which a three-dimensional position marking system, of the probe type, makes it possible to mark the three-dimensional position coordinates of a nonhomogeneous structure, such as the head of a patient having to undergo a neurosurgical intervention, and then to put into correspondence as a function of the relative position of the nonhomoc.eneous structure a series of corresponding images consisting of two-dimensional images sectioned along an arbitrary direction, and obtained previously with the aid of a medical imaging method of the "scanner" type.

The system and the operational mode mentioned above offer a sure advantage for the intervening surgeon since the latter has available, during the intervention, apart from a direct view of the intervention, at least one two-dimensional sectional view enabling him to be aware, in the sectional plane, of the state of performance of the intervention.

However, and by virtue of the very design of the system and of the operational mode mentioned above, the latter allow neither a precise representation of the state of performance of the intervention, nor partially or totally automated conduct of the intervention in accordance with a program for advance of the instrument determined prior to the intervention.

Such a system and such an operational mode cannot therefore claim to eradicate all man-made risk, since the intervention is still conducted by the surgeon alone.

The objective of the present invention is to remedy the whole of the problem cited earlier, and in particular to propose a system permitting as exact as possible a correlation, at any instant, between an intervention modeling on the screen and the actual intervention, and furthermore the representation from one or more viewing angles, and if appropriate in one or more sectional planes, of the nonhomogeneous structure, the sectional plane or planes possibly being for example perpendicular to the direction of the path of advance of the instrument or of the intervention tool.

Another objective of the present invention is also the implementation of a system permitting simulation of an optimal trajectory of advance of the tool, so as to constitute an assisted or fully programed intervention.

Finally, an objective of the present invention is to propose a system making it possible, on the basis of the simulated trajectory and of the programed intervention, to steer the movement of the instrument or tool to the said trajectory so as to carry out the programed intervention.

The invention proposes to this effect an interactive system for local intervention inside a region of a nonhomogeneous structure to which is tied a reference structure containing a plurality of base points, characterized in that it comprises:

- means of dynamic display by three-dimensional imaging of a representation of the nonhomogeneous structure and of a reference structure tied to the nonhomogeneous structure, including images of the base points,
- means of delivering the coordinates of the images of the base points in the first reference frame,
- means of securing the position of the non-homogeneous structure and the reference structure with respect to a second reference frame.
- marker means for delivering the coordinates of the base points in the second reference frame,
- means of intervention comprising an active member whose position is determined with respect to the second reference frame,
- means of optimizing the transfer of reference frames from the first reference frame to the second reference frame and vice versa, on the basis of the coordinates of the images of the base points in the first reference frame and of the coordinates of the base points in the second reference frame, in such a way as to reduce to a minimum the deviations between the coordinates of the images of the base points in the first reference frame and the coordinates of the base points, expressed in the said first reference frame with the aid of the said reference frame transfer tools,
- means for defining with respect to the first reference frame a simulated origin of intervention and a simulated direction of intervention, and
- reference frame transfer means using the said reference frame transfer tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

A more detailed description of the system of the invention will be given below with reference to the drawings in which:

FIG. 1 represents a general view of an interactive system for local intervention inside a region of a nonhomogeneous structure according to the present invention,

FIG. 2 represents, in the case where the nonhomogeneous Structure consists of the head of a patient, and with a view to a neurosurgical intervention, a reference structure tied to the nonhomogeneous structure and enabling a correlation to be established between a "patient" reference frame and a reference frame of images of the patient which were made and stored previously,

FIG. 3 represents an advantageous embodiment of the spacial distribution of the reference structure of FIG. 2,

FIG. 4 preesents an advantageous embodiment of the intervention means set up on an operating table in the case of a neurosirgical intervention,

FIGS. 5*a* and 5*b* represent a general flow diagram of functional steps implemented by the system,

FIGS. **6** thru **8** represent flow diagrams of programs permitting implementation of certain functional steps of FIG. **5***b,*

FIG. **9***a* represents a flow diagram of a program permitting implementation of a functional step of FIG. **5***a,*

FIG. **9***b* represents a flow diagram of a program permitting implementation of another functional step of FIG. **5***a,*

FIGS. **10***a* and **10***b* represent a general flow diagram of the successive steps of an interactive dialogue between the system of the present invention and the intervening surgeon and

FIG. **10***c* represents a general flow diagram of the successive functional steps carried out by the system of the invention, having (sic) the intervention, prior to the intervention, during the intervention and after the intervention.

The interactive system for local intervention according to the invention will firstly be described in connection with FIG. **1**.

A nonhomogeneous structure, denoted SNH, on which an intervention is to be performed, consists for example of the head of a patient in which a neurosurgical intervention is to be performed. It is however understood that the system of the invention can be used to carry out any type of intervention in any type of nonhomogeneous structure inside which structural and/or functional elements or units may be in evidence and whose integrity, during the intervention, is to be respected as far as possible.

The system comprises means, denoted **1**, of dynamic display by three-dimensional imaging, with respect to a first reference frame R_1, of a representation (denoted RSR) of a reference structure SR (described later) tied to the structure SNH, and a representation or modeling of the nonhomogeneous structure, denoted RSNH.

More precisely, the means 1 make it possible to display a plurality of successive three-dimensional images, from different angles, of the representations RSNH and RSR.

The system of the invention also comprises means, denoted **2**, of tied positioning, with respect to a second reference frame R_2, of the structures SNH and SR.

In the present non-limiting example, the head of the patient, bearing the reference structure SR, is fixed on an operating table TO to which are fixed the means **2** of tied positioning.

Of course, the patient whose head has been placed in the means **2** for tied positioning has previously been subjected to the customary preparations, in order to enable him to undergo the intervention.

The means **2** of the tied positioning with respect to R_2 will not be described in detail since they can consist of any means (such as a retaining headset) normally used in the field of surgery or neurosurgery. The reference frame R_2 can arbitrarily be defined as a tri-rectangular reference trihedron tied to the operating table TO, as represented in FIG. **1**.

Means **3** of marking, with respect to the second reference frame R_2, the coordinates, denoted X2, Y2, Z2, of arbitrary points, and in particular of a certain number of base points of the reference structure SR are furthermore provided.

These base points constituting the reference structure SR can consist of certain notable points and/or of marks fixed to the patient, at positions selected by the surgeon and in particular at these notable points.

The system of the invention further comprises computing means **4** receiving means **3** of marking the coordinates X2, X2, Z2.

The computing means **4**, as will be seen in detail later, are designed to elaborate optimal tools for reference frame transfer using on the one hand the coordinates in R_2, measured by the probe **3**, of a plurality of base points of the structure SR, and on the other hand the coordinates in R_1, determined by graphical tools of the computer **M01** (pointing by mouse, etc.), of the images of the corresponding base points in the representation RSR, so as to secure the best possible correlation between the information modeled in the computer equipment and the corresponding real-world information.

There is furthermore provision for reference frame transfer means **11** designed to use the tools thus elaborated and to secure this correlation in real time.

Moreover, means **40** are provided, as will be seen in detail later, for determining or modeling a reference origin of intervention ORI and a direction of intervention Δ.

With the aid of the means **11**, the modeled direction of intervention Δ can, at least prior to the intervention and at the start of the intervention, be materialized through an optical sighting system available to the surgeon, it being possible to steer this sighting system positionally with respect to the second reference frame R_2.

The sighting system will be described later.

The system of the present invention finally comprises means **5** of intervention comprising an active member, denoted **50**, whose position is specified with respect to the second reference frame R_2. The active member can consist of the various tools used in surgical intervention. For example, in the case of an intercranial neurosurgical intervention, the active member could be a trephining tool, a needle, a laser or radioscope emission head, or an endoscopic viewing system.

According to an advantageous characteristic of the invention, by virtue of the reference frame transfer means **11**, the position of the active member can be controlled dynamically on the basis of the prior modeling of the origin of intervention ORI and of the direction of intervention Δ.

The means **1** of dynamic display by three-dimensional imaging of the representations RSNH and RSR comprise a file **10** of two-dimensional image data. The file **10** consists for example of digitized data from tomographic sections, from radiographs, from maps of the patient's head, and contained in an appropriate mass memory.

The successive tomographic sections can be produced prior to the intervention in a conventional manner, after the reference structure SR has been put in place on the nonhomogeneous structure SNH.

According to an advantageous feature, the reference structure SR can consist of a plurality of marks or notable points which can be both sensed by the marker means **3** and detected on the two-dimensional images obtained.

Of course, the abovementioned two-dimensional tomographic sections can likewise be produced by any medical imaging means such as a nuclear magnetic resonance system.

In a characteristic and well-known manner, each two-dimensional image corresponding to a tomographic scanner section corresponds to a structural slice thickness of about 2 to 3 mm, the pixels or image elements in the plane of the tomographic section being obtained with a precision of the order of ±1 mm. It is therefore understood that the marks or points constituting the reference structure SR appear on the images with a positional uncertainty, and an important feature of the invention will consist in minimizing these uncertainties as will be described later.

The system also comprises first means **110** for calculating and reconstructing three-dimensional images from the data from the file **10**.

It also comprises a high-resolution screen **12** permitting the displaying of one or more three-dimensional or two-dimensional images constituting so many representations of the reference structure RSR and of the nonhomogeneous structure SNH.

Advantageously, the calculating means **110**, the high-resolution screen and the mass memory containing the file **10** form part of a computer of the workstation type with conventional design and denoted MO1.

Preferably, the first calculating means **110** can consist of a CAD type program installed in the workstation MO1.

By way of non-limiting example, this program can be derived from the software marketed under the tradename "AUTOCAD" by the "AUTODESK" company in the United States of America.

Such software makes it possible, from the various digitized two-dimensional images, to reconstruct threedimensional images constituting the representations of the structures RSR and RSNH in arbitrary orientations.

Thus, as has furthermore been represented in FIG. **1**, the calculating means **4** and **11** can consist of a third computer, denoted MO2 in FIG. **1**.

The first and second computers MO1 and MO2 are interconnected by a conventional digital link (bus or network).

As a variant, the computers MO1 and MO2 can be replaced by a single workstation.

The marker means **3** consist of a three-dimensional probe equipped with a tactile tip **30**.

This type of three-dimensional probe, known per se and not described in detail, consists of a plurality of hinged arms, marked in terms of position with respect to a base integral with the operating table TO. It makes it possible to ascertain the coordinates of the tactile tip **30** with respect to the origin O_2 of the reference frame R_2 with a precision better than 1 mm.

The probe is for example equipped with resolvers delivering signals representing the instantaneous position of the abovementioned tactile tip **30**. The resolvers are themselves connected to the circuits for digital/analog conversion and sampling of the values representing these signals, these sampling circuits being interconnected in conventional manner to the second computer MO2 in order to supply it with the coordinates **X2**, **X2**, **Z2** of the tactile tip **30**.

As a variant or additionally, and as represented diagrammatically, the marker means **3** can comprise a set of video cameras **31** and **32** (or else infrared cameras) enabling pictures to be taken of the structures SNH and SR.

The set of cameras can act as a stereoscopic system permitting the positional plotting of the base points of the reference structure SR, or of other points of the nonhomogeneous structure SNH, with respect to the second reference frame R_2. The positional plotting can be done for example by appending a laser beam emission system making it possible to illuminate successively the points whose coordinates are sought, appropriate software making it possible to then determine the position of these points one by one with respect to R_2. This software will not be described since it can consist of position and shape recognition software normally available on the market.

According to another variant, the marker means **3** can comprise a telemetry system.

In this case, the marks of the structure SR can consist of small radiotransmitters implanted for example on the relevant points of the patient's head and designed to be visible on the two-dimensional images, appropriate electromagnetic or optical sensors (not shown) being provided in order to determine the coordinates of the said marks in the reference frame R_2 or in a reference frame tied to the latter.

It is important to note here that the general function of the base points of the reference structure is, on the one hand, to be individually localizable on the reference structure, in order to deduce from this the coordinates in R_2, and on the other hand, to be visualizable on the two-dimensional images so as to be identified (by their coordinates in R_1) and included in the representation RSR on the screen.

It can therefore involve special marks affixed at arbitrary points of the lateral surface of the structure SNH, or else at notable points of the latter, or else, when the notable points can in themselves be localized with high precision both on the structure SNH and on the **2D** sections, notable points totally devoid of marks.

In FIG. **2** a plurality of marks, denoted **M1** to Mi, these marks, in the case where the nonhomogeneous structure consists of the head of a patient, being localized for example between the eyebrows of the patient, on the latter's temples, and at the apex of the skull at a notable point such as the frontal median point.

More generally, for a substantially ovoid volume constituting the nonhomogeneous structure, there is advantageously provision for four base points at least on the outer surface of the volume.

Thus, as has been represented in FIG. **3**, the four marks M1 to M4 of the reference structure are distributed so as preferably to define a more or less symmetric tetrahedron. The symmetry of the tetrahedron, represented in FIG. **3**, is materialized by the vertical symmetry plane PV and the horizontal symmetry plane PH.

According to an advantageous characteristic, as will be seen later, the means of elaborating the reference frame transfer tools are designed to select three points of the tetrahedron which will define the "best plane" for the reference frame transfer.

Also, the presence of four or more points enables the additional point(s) to validate a specified selection.

More precisely, the presence of a minimum of four base points on the reference structure makes it possible to search for the minimum distortion between the points captured on the patient by the marker means consisting for example of the three-dimensional probe and the images of these points on the representation by three-dimensional imaging, the coordinates of which are calculated during processing. The best plane of the tetrahedron described earlier, that is to say the plane for which the uncertainty in the coordinates of the points between the points actually captured by the three-dimensional probe and the points of the representation of the reference structure RSR, is minimal, then becomes the reference plane for the reference frame transfer. Thus, the best correlation will be established between a modeled direction of intervention and a modeled origin of intervention, on the one hand, and the action of the member **50**. Preferably, the origin of intervention will be placed at the center of the region in which the intervention is to be carried out, that is to say a tumor observed or treated for example.

Furthermore, it will be possible to take the noted residual uncertainty into account in order to effect the representation of the model and of the tools on the dynamic display means.

A more detailed description of the means of intervention **5** will now be given in connection with FIG. **4**.

Preferably, the means of intervention **5** comprise a carriage **52** which is translationally mobile along the operating table TO, for example on a rack, denoted **54**, whilst being driven by a motor, not shown, itself controlled by the computer MO2 for example, via an appropriate link. This

movement system will not be described in detail since it corresponds to a conventional movement system available on the market. As a variant, the carriage **52** can be mobile over a distinct path separated from the operating table TO, or immobile with respect to the operating table and then constitute a support.

The support carriage **52** comprises in the first place a sighting member OV, constituting the above-mentioned sighting system, which can consist of a binocular telescope.

The sighting member OV enables the surgeon, prior to the actual intervention, or during the latter, to sight the presumed position of the region in which the intervention is to be carried out.

Furthermore, and in a non-limiting manner, with the sighting member OV can be associated a helium-neon laser emission system, denoted EL, making it possible to secure the aiming of a fine positioning or sighting laser beam on the structure SNH and in particular, as will be seen in detail later, to indicate to the surgeon the position of an entry point PE prior to the intervention, to enable the latter to open the skull at the appropriate location, and likewise to indicate to him what the direction of intervention will be. Additionally, the illuminating of the relevant point of the nonhomogeneous structure or at the very least the lateral surface of the latter enables the video cameras **31** and **32** to carry out, if necessary, a positional plotting.

Preferably, a system for measuring position by telemetry **53** is provided to secure the precise measurement of the position of the support carriage **52** of the sighting member OV and of the laser emission system EL. During the operation, and in order to secure the intervention, the carriage **52** can be moved along the rack **54**, the position of the carriage **52** being measured very precisely by means of the system **53**. The telemetry system **53** is interconnected with the microcomputer MO2 by an appropriate link.

The means of intervention **5** can advantageously consist of a guide arm **51** for the active member **50**.

The guide arm **51** can advantageously consist of several hinged segments, each hinge being equipped with motors and resolvers making it possible to secure control of movement of the end of the support arm and the positional plotting of this same end and therefore of the active member **50** according to six degrees of freedom with respect to the carriage **52**. The six degrees of freedom comprise, of course, three translational degrees of freedom with respect to a reference frame tied to the carriage **52** and three rotational degrees of freedom along these same axes.

Thus, the support arm **51** and the member **50** are marked in terms of instantaneous position with respect to the second reference frame R_2, on the one hand by way of the positional plot of the mobile carriage **52** and, on the other hand, by way of the resolvers associated with each hinge of the support arm **51**.

In the case of an intracranial neurosurgical surgical intervention, the active member **50** can be removed and can consist of a trephining tool, a needle or radioactive or chemical implant, a laser or radioisotope emission head or an endoscopic viewing system. These various members will not be described since they correspond to instruments normally used in neurosurgery.

The materializing of the modeled direction of intervention can be effective by means of the laser emitter EL. This sighting being performed, the guide arm **51** can then be brought manually or in steered manner into superposition with the direction of intervention Δ.

In the case of manual positioning, the resolvers associated with the sighting member OV and the laser emitter EL, if appropriate, make it possible to record the path of the sighting direction, constituting in particular the actual direction of intervention, on the representation of the nonhomogeneous structure in the dynamic display means **1**.

Furthermore, as will be described later and in preferential manner, the intervening surgeon will be able firstly to define a simulated intervention path and steer thereto the movements of the active member **50** in the nonhomogeneous structure in order effectively to secure all or part of the intervention.

In this case, the progress of the intervention tool **50** is then steered directly to the simulated path (data ORI, Δ) by involving the reference frame transfer means **11** in order to express the path in the reference frame R_2.

A more detailed description of the implementation of the operational mode of the system of the invention will now be described in connection with FIGS. **5***a* and **5***b*.

According to FIG. **5***a*, the first step consists in obtaining and organizing in memory the two-dimensional image data (step **100**). Firstly, the nonhomogeneous structure SNH is prepared. In the case of a neurosurgical intervention for example, this means that the patient's head can be equipped with marks constituting the base points of the reference structure SR. These marks can be produced by means of points consisting of a dye partially absorbing the X-rays, such as a radiopaque dye.

The abovementioned marks are implanted by the surgeon on the patient's head at notable points of the latter [sic], and images can then be taken of the nonhomogeneous structure SNH by tomography for example, by means of an apparatus of the X-ray scanner type.

This operation will not be described in detail since it corresponds to conventional operations in the field of medical imaging.

The two-dimensional image data obtained are then constituted as digitized data in the file **10**, these data being themselves marked with respect to the reference frame R_1 and making it possible, on demand, to restore the two-dimensional images onto the dynamic display means **1**, these images representing superimposed sections of the nonhomogeneous structure SNH.

From the digitized image data available to the surgeon, the latter then proceeds, as indicated at **101** in FIG. **5***a*, to select the structures of interest of the abovementioned images.

The purpose of this step is to facilitate the work of the surgeon by forming three-dimensional images which contain only the contours of the elements of the structure which are essential for geometrical definition and real-time monitoring of the progress of the intervention.

In the case where the nonhomogeneous structure SNH consists of the head of a patient, an analysis of the two-dimensional image data makes it possible, from values of optical density of the corresponding image-points, straightaway to extract the contours of the skull, to check the distance scales, etc.

Preferably, the abovementioned operations are performed on a rectangle of interest for a given two-dimensional image, this making it possible, by moving the rectangle of interest, to cover the whole of the image.

The above analysis is performed by means of suitable software which thus makes it possible to extract and vectorize the contours of the structures which will be modeled in the representations RSNH and RSR.

The structures modeled in the case of a neurosurgical intervention are for example the skull, the cerebral ventricles, the tumor to be observed or treated, the falx cerebri, and the various functional regions.

According to a feature of the interactive system of the invention, the surgeon may have available a digitizing table or other graphics peripheral making it possible, for each displayed two-dimensional image, to rectify or complete the definition of the contour of a particular region of interest.

It will be noted finally that by superimposing the extracted contours on the displayed two-dimensional image, the surgeon will be able to validate the extractions carried out.

The extracted contours are next processed by sampling points to obtain their coordinates in the reference frame R_1, it being possible to constitute these coordinates as an ASCII type file. This involves step **102** for generating the three-dimensional data base.

This step is followed by a step **103** of reconstructing the three-dimensional model. This step consists firstly, with the aid of the CAD type software, in carrying out on the basis of the contours of the structures of interest constituted as vectorized two-dimensional images an extrapolation between the various sectional planes.

The abovementioned extrapolation is carried out preferably by means of a "B-spline" type algorithm which seems best suited. This extrapolation transforms a discrete item of information, namely the successive sections obtained by means of the scanner analysis, into a continuous model permitting three-dimensional representation of the volume envelopes of the structures.

It should be noted that the reconstruction of the volumes constituting the structures of interest introduces an approximation related in particular to the spacing and non-zero thickness of the acquisition sections. An important characteristic of the invention, as explained in detail elsewhere, is on the one hand to minimize the resulting uncertainties in the patient-model correlation, and on the other hand to take into account the residual uncertainties.

The CAD type software used possesses standard functions which enable the model to be manipulated in space by displaying it from different viewpoints through just a criterion defined by the surgeon (step **104**).

The software can also reconstruct sectional representation planes of the nonhomogeneous structure which differ from the planes of the images from the file **10**, this making it possible in particular to develop knowledge enhancing the data for the representation by building up a neuro-anatomical map.

The surgeon can next (step **105**) determine a model of intervention strategy taking into account the modeled structures of interest, by evaluating the distance and angle ratios on the two-and three-dimensional representations displayed.

This intervention strategy will consist, in actual fact, on the one hand in localizing the tumor and in associating therewith a "target point", which will subsequently be able to substitute for the origin common to all the objects (real and images) treated by the system, and on the other hand in determining a simulated intervention path respecting to the maximum the integrity of the structures of interest. This step can be carried out "in the office", involving only the workstation.

Once this operation is performed and prior to the intervention, the following phase consists in implementing the steps required to establish as exact as possible a correlation between the structure SNH (real world) and the representation RSNH (computer world). This involves steps **106** to **109** of FIG. *5b*.

Firstly, as represented in FIG. *5b* at step **107**, marking of the base points of the reference structure SR with respect to the second reference frame is carried out with the aid of the marker means **3**, by delivering to the system the coordinates X2, Y2, Z2 of the said base points.

The following step **106** consists in identifying on the representations RSNH and RSR displayed on the screen the images of the base points which have just been marked. More precisely, with the aid of appropriate graphics peripherals, these representations (images) of the base points are selected one by one, the workstation supplying on each occasion (in this instance to the computer MO2) the coordinates of these points represented in the reference frame R_1.

Thus the computer MO2 has available a first set of three-dimensional coordinates representing the position of the base points in R_2, and a second set of three-dimensional coordinates representing the position of the representations of the base points in R_1.

According to an essential feature of the invention, these data will be used to elaborate at **108, 109**, tools for reference frame transfer (from R_1 to R_2 and vice versa) by calling upon an intermediate reference frame determined from the base points and constituting an intermediate reference frame specific to the reconstructed model.

More precisely, the intermediate reference frame is constructed from three base points selected so that, in this reference frame, the coordinates of the other base points after transfer from R_2 and the coordinates of the representations of these other base points after transfer from R_1 are expressed with the greatest consistency and minimum distortion.

When the step of elaborating the reference frame transfer tools is concluded, these tools can be used by he system to secure optimal coupling between the real world and the computer world (step **1110**).

Furthermore, according to a subsidiary feature of the present invention, the system can create on the display means a representation of the nonhomogeneous structure and of the intervention member which takes account of the deviations and distortions remaining after the "best" reference frame transfer tools have been selected (residual uncertainties). More precisely, from these deviations can be deduced by the calculating means a standard error likely to appear in the mutual positioning between the representation of the nonhomogeneous structure and the representation of elements (tools, sighting axes, etc.) referenced on R_2 when using the reference frame transfer tools. This residual uncertainty, which may in practice be given substance through an error matrix, can be used for example to represent certain contours (tool, structures of interest to be avoided during the intervention, etc.) with dimensions larger than those which would normally be represented starting from the three-dimensional data base or with the aid of coordinates marked in R_2, the said larger dimensions being deduced from the "normal" dimensions by involving the error matrix. For example, if the member were represented normally, in transverse section, by a circle of diameter D1, a circle of diameter D2>D1 can be represented in substance, with the difference D2-D1 deduced from the standard error value. In this way, when a direction of intervention will be selected making it possible to avoid traversing certain structures of interest, the taking into account of an "enlarged" size of the intervention tool will eradicate any risk of the member, because of the abovementioned errors, accidently traversing these structures.

Back at step **105**, and as will be seen in more detail with reference to FIGS. *9a* and *9b*, the reference origin of intervention ORI and the direction of intervention Δ, that is to say the simulated intervention path, can be determined according to various procedures.

According to a first procedure, the trajectory can be defined from two points, namely an entry point PE (FIG. **3**)

and a target point, that is to say substantially the center of the structure of interest consisting of the tumor to be observed or treated. Initially, these two points are localized on the model represented on the screen.

According to a second methodology, the trajectory can be determined from the abovementioned target point and from a direction which takes account of the types of structures of interest and of their positions with a view to optimally respecting their integrity.

After the abovementioned step **108**, the surgeon can at step **1110** perform the actual intervention.

The intervention can advantageously be performed by steering the tool or active member over the simulated intervention path, determined in step **1110**.

As a variant, given that the support arm **51** for the active member, equipped with its resolvers, continuously delivers the coordinates in R_2 of the said active member to the system, it is also possible to perform the operation manually or semi-manually, by monitoring on the screen the position and motions of a representation of the tool and by comparing them with the simulated, displayed intervention path.

It will furthermore be noted that the modeled direction of intervention can be materialized with the aid of the laser beam described earlier, the positioning of the latter (with respect to R_2) being likewise carried out by virtue of the reference frame transfer tools.

Certain functional features of the system of the invention will now be described in further detail with reference to FIGS. **6**, **7**, **8**, **9***a* and **9***b*.

The module for elaborating the reference frame transfer tools (steps **108**, **109** of FIG. **5***b*) will firstly be described with reference to FIG. **6**.

This module comprises a first sub-module **1001** for acquiring three points A, B, C, the images of the base points of SR on the representation RSNH (the coordinates of these points being expressed in the computer reference frame R_1), by successive selections of these points on the representation. To this effect, the surgeon is led, by means of a graphics interface such as a "mouse" to point successively at the three selected points A, B, C.

The module for preparing the transfer tools also comprises a second sub-module, denoted **1002**, for creating a unit three-dimensional orthogonal matrix M, this matrix being characteristic of a right-handed orthonormal basis represented by three unit vectors $\vec{i}$, $\vec{j}$, $\vec{k}$, which define an intermediate reference frame tied to R_1.

The unit vectors $\vec{i}$, $\vec{j}$ and $\vec{k}$ are given by the relations:

$$\vec{j} = \vec{AB} / \|\vec{AB}\|$$

$$\vec{k} = \left(\vec{BA} \wedge \vec{BC} \right) / \| \vec{BA} \wedge \vec{BC} \|$$

$$\vec{i} = \vec{j} \wedge \vec{k}$$

where $\| \ \|$ designates the norm of the relevant vector.

In the above relations, the sign "$\wedge$" designates the vector product of the relevant vectors.

Similarly, the module for preparing the transfer tools comprises a third sub-module, denoted **1003**, for acquiring three base points D, E, F, of the structure SR, these three points being those whose images on the model are the points A, B, C respectively. For this purpose, the surgeon, for example by means of the tactile tip **30**, successively senses these three points to obtain their coordinates in R_2.

The sub-module **1003** is itself followed, as represented in FIG. **6**, by a fourth sub-module **1004** for creating a unit three-dimensional orthogonal matrix N, characteristic of a right-handed orthonormal basis comprising three unit vectors $\vec{i}'$, $\vec{j}'$, $\vec{k}'$ and which is tied to the second reference frame R_2 owing to the fact that the nonhomogeneous structure SNH is positionally tied with respect to this reference frame.

The three unit vectors $\vec{i}'$, $\vec{j}'$, $\vec{k}'$ are defined by the relations:

$$\vec{j}' = \vec{DE} / \|\vec{DE}\|$$

$$\vec{k}' = \left(\vec{ED} \wedge \vec{EF} \right) / \| \vec{ED} \wedge \vec{EF} \|$$

$$\vec{i}' = \vec{j}' \wedge \vec{k}'$$

As indicated above, to the extent that the base points of the reference structure can be marked in R_2 with high precision, so their representation in the computer base R_1 is marked with a certain margin of error given on the one hand the non-zero thickness (typically from 2 to 3 mm) of the slices represented by the two-dimensional images from the file **10**, and on the other hand (in general to a lesser extent) the definition of each image element or pixel of a section.

According to the invention, once a pair of transfer matrices M, N has been elaborated with selected points A, B, C, D, E, F, it is sought to validate this selection by using one or more additional base points; more precisely, for the or each additional base point, this point is marked in R_2 with the aid of the probe **30**, the representation of this point is marked in R_1 after selection on the screen, and then the matrices N and M are applied respectively to the coordinates obtained, in order to obtain their expressions in the bases ($\vec{i}'$, $\vec{j}'$, $\vec{k}'$) and ($\vec{i}$, $\vec{j}$, $\vec{k}$) respectively. If these expressions are in good agreement, these two bases can be regarded as a single intermediate reference frame, this securing the exact as possible mathematical coupling between the computer reference frame R_1 tied to the model and the "real" reference frame R_2 tied to the patient.

In practice, the module for elaborating the reference frame transfer tools can be designed to perform steps **1001** to **1004** in succession on basic triples which differ on each occasion (for example, if four base points have been defined associated with four representations in RSR, there are four possible triples), in order to perform the validation step **1005** for each of these selections and finally in order to choose the triple for which the best validation is obtained, that is to say for which the deviation between the abovementioned expressions is smallest. This triple defines the "best plane" mentioned elsewhere in the description, and results in the "best" transfer matrices M and N.

As a variant, it will be possible for the selection of the best plane to be made at least in part by the surgeon by virtue of his experience.

It should be noted that the reference frame transfer will only be concluded by supplementing the matrix calculation with the matrices M, N with a transfer of origin, so as to create a new common origin for example at the center of the tumor to be observed or treated (point ORI). This transfer of origin is effected simply by appropriate subtraction of vectors on the one hand on the coordinates in R_1, and on the other hand on the coordinates in R_2. These vectors to be subtracted are determined after localization of the center of the tumor on the representation.

Furthermore, the means described above for establishing the coupling between the patient's world and the model's world can also be used to couple to the model's world that of map data, also stored in the workstation and expressed in a different reference frame denoted R_3. In this case, since these data contain no specific visible mark, the earlier described elaboration of matrices is performed by substituting for these marks the positions of notable points of the patient's head. These may be temporal points, the frontal median point, the apex of the skull, the center of gravity of the orbits of the eyes, etc.

The corresponding points of the model can be obtained either by selection by mouse or graphics tablet on the model, or by sensing on the patient himself and then using the transfer matrices.

The above step of elaborating the reference frame transfer tools, conducted in practice by the calculating means **4**, makes it possible subsequently to implement the reference frame transfer means (FIGS. **7** and **8**).

With reference to FIG. **7**, the first transfer sub-module **201** comprises a procedure denoted **2010** for aquiring the coordinates XM, YM, ZM, expressed in R_1, of the point to be transferred, by selecting on the representation.

The procedure **2010** followed by a procedure **2011** for calculating the coordinates XP, YP, ZP (expressed in R_2) of the corresponding real point on the patient through the transformation:

{XP, YP, ZP}=$M*N^{-1}*${XM, YM, ZM} where $M * N^{-1}$ represents the product of the matrix M and the inverse matrix N.

The procedure **2011** is followed by a processing procedure **2012** utilizing the calculated coordinates XP, YP, ZP, for example to indicate the corresponding point on the surface of the structure SNH by means of the laser emission system EL, or again to secure the intervention at the relevant point with coordinates XP, YP, ZP (by steering the active member).

Conversely, in order to secure a transfer from SNH to RSNH, the second sub-module **202** comprises (FIG. **8**) a procedure denoted **2020** for acquiring on the structure SNH the coordinates XP, YP, ZP (expressed in R_2) of a point to be transferred.

These coordinates can be obtained by means of the tactile tip **30** for example. The procedure **2020** is followed by a procedure **2021** for calculating the corresponding coordinates XM, YM, ZM in R_1 through the transformation:

{XM, YM, ZM}=$N*M^{-1}*${XP, YP, ZP}

A procedure **2022** next makes it possible to effect the displaying of the point with coordinates XM, YM, ZM on the model or again of a straight line or of a plane passing through this point and furthermore meeting other criteria.

It will be noted here that the two sub-modules **201, 202** can used [sic] by the surgeon at any moment for the purpose of checking the valid nature of the transfer tools; in particular, it is possible to check at any time that a real base point, with coordinates known both in R_2 and R_1 (for example a base point of SR or an arbitrary notable point of the structure SNH visible on the images), correctly relocates with respect to its image after transferring the coordinates in step **2011**.

In the event of an excessive difference, a new step of elaboration of the transfer tools is performed.

Furthermore, the sub-modules **201, 202** can be designed to also integrate the taking into account of the residual uncertainty, as spoken of above, so as for example to represent on the screen a point sensed not in a pointwise manner, but in the form for example of a circle or a sphere representing the said uncertainty.

From a simulated intervention path, for example on the representation RSNH, or from any other straight line selected by the surgeon, the invention furthermore enables the model to be represented on the screen from a viewpoint corresponding to this straight line. Thus the third transfer subroutine comprises, as represented in FIGS. **9***a* and **9***b*, a first module **301** for visualizing the representation in a direction given by two points and a second module **302** for visualizing the representation in a direction given by an angle of elevation and an angle of azimuth.

The first module **301** for visualizing the representation in a direction given by two points comprises a first sub-module denoted **3010** permitting acquisition of the two relevant points which will define the selected direction. The coordinates of these points are expressed in the reference frame R_1, these points having either been acquired previously on the nonhomogeneous structure SNH for example by means of the tactile tip **30** and then subjected to the reference frame transfer, or chosen directly on the representation by means of the graphics interface of the "mouse" type.

The first sub-module **3010** is followed by a second sub-module denoted **3011** permitting the creation of a unit, orthogonal three-dimensional matrix V characteristic of a right-handed orthonormal basis $\vec{i}''$, $\vec{j}''$, $\vec{k}''$ the unit vectors $\vec{i}''$, $\vec{j}''$, $\vec{k}''$, being determined through the relations:

$$\vec{k}'' = \vec{AB}/\|\vec{AB}\|;$$

$$\vec{i}'' \cdot \vec{k}'' = O; \vec{i}'' \cdot \vec{z}'' = O; \|\vec{i}''\| = 1;$$

$$\vec{j}'' = \vec{k}'' \Lambda \vec{j}''$$

where "Λ" represents the vector product and "." symbolizes the scalar product.

The sub-module **3011** is followed by a routine **3012** making it possible to secure for all the points of the entities (structures of interest) of the three-dimensional data base of coordinates XW, YW, ZW in R_1 a conversion into the orthonormal basis ($\vec{i}''$, $\vec{j}''$, $\vec{k}''$) by the relation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The subroutine **3013** is then followed by a subroutine **3014** for displaying the plane i", j", the subroutines **3013** and **3014** being called up for all the points, as symbolized by the arrow returning to block **3012** in FIG. **9***a*.

When all the points have been processed, an output module **3015** permits return to a general module, which will be described later in the description. It is understood that this module enables two-dimensional images to be reconstructed in planes perpendicular to the direction defined by A and B.

In the same way, the second module **302** (FIG. **9***b*) for visualizing the representation from a viewpoint given by an angle of elevation and an angle of azimuth comprises a first sub-module **3020** for acquiring the two angles in the representation frame of reference.

The selection of the angles of elevation and of azimuth can be made by selecting from a predefined data base or by moving software cursers associated with each view or else by modification relative to a current direction, such as the modeled direction of intervention. The sub-module **3020** is itself followed by a second sub-module **3021** for creating a unit orthoganal three-dimensional matrix W characteristic of a right-handed orthonormal basis of unit vectors $\vec{i}'''$, $\vec{j}'''$, $\vec{k}'''$. They are defined by the relations:

$\vec{i}''' \cdot \vec{k}''' = O;$

$\vec{k}''' \cdot \vec{z}''' = \sin(\text{azimuth})$

$\vec{j}''' \cdot \vec{z}''' = O;$

$\vec{i}''' \cdot \vec{y} = \cos(\text{elevation});$

$\vec{i}'''' \cdot \vec{x}''' = \sin(\text{elevation})$

$\vec{j}''' = \vec{k}''' \wedge \vec{i}'''$

A routine **3022** is then called for all the points of the entities of the three-dimensional data base of coordinates XW, YW, ZW and enables a first sub-routine **3023** to be called permitting calculation of the coordinates of the relevant point in the right-handed orthonormal bases $\vec{i}'''$, $\vec{j}'''$ $\vec{k}'''$ through the transformation:

{XV, YV, ZV}=V*{XW, YW, ZW}

The sub-routine **3023** is itself followed by a sub-routine **3024** for displaying the plane i''', j''', the two sub-routines **3023** and **3024** then being called up for each point as symbolized by the return via the arrow to the block **3022** for calling the abovementioned routine. When all the points have been processed, an output sub-module **3025** permits a return to the general menu.

Of course, all of the programs, sub-routines, modules, sub-modules and routines destroyed earlier are managed by a general "menu" type program so as to permit interactive driving of the system by screen dialogue with the intervening surgeon by specific screen pages.

A more specific description of a general flow diagram illustrating this general program will now be given in connection with FIGS. **10***a* and **10***b*.

Thus, in FIG. **10***a* has been represented in succession a screen page **4000** relating to the loading of data from the digitized file **10**, followed by a screen page **4001** making it possible to secure the parameterizing of the grey scales of the display on the dynamic display means **1** and to calibrate the image, for example.

The screen page **4001** is followed by a screen page **4002** making it possible to effect the generation of a global view and then a step or screen page **4003** makes it possible to effect an automatic distribution of the sections on the screen of the workstation.

A screen page **4004** makes it possible to effect a manual selection of sections and then a screen page **4005** makes it possible to effect the selection of the strategy (search for the entry points and for the possible directions of intervention, first localizing of the target (tumor . . .) to be treated . . .), as defined earlier, and to select the position and horizontal, sagittal and frontal distribution of the sections.

A screen page **4006** also makes it possible to effect a display of the settings of a possible stereotaxic frame.

It will be recalled that the reference structure SR advantageously replaces the stereotaxic frame formerly used to effect the marking of position inside the patient's skull.

There may furthermore be provided a screen-page **4007** for choosing strategic sections by three-dimensional viewing, on selection by the surgeon, and then at **4008** the aligning of the references of the peripherals (tool, sighting members, etc., with the aid of the probe **30**.

A screen page **4009** is also provided to effect the search for the base points on the patient with the aid of the said probe, following which the steps of construction of the reference frame transfer tools and of actual reference frame transfer are performed, preferably in a user-transparent manner.

Another screen page **4010** is then provided, so as to effect the localizing of the target on the representation (for example a tumor to be observed or treated in the case of a neurosurgical intervention) in order subsequently to determine a simulated intervention path.

Then a new screen page **4011** makes it possible to effect the setting of the guides for the tool on the basis of this simulated path before opening up the skin and bone flaps on the patient's skull.

Then a new localizing step **4012** makes it possible to check whether the position of the guides corresponds correctly to the simulated intervention path.

The screen page **4012** is followed by a so-called intervention screen page, the intervention being performed in accordance with step **1110** of FIG. **5***b*.

A more detailed description of the interactive dialogue between the surgeon and the system during a surgical, and in particular a neurosurgical, intervention will follow with reference to FIG. **10***c* and to all of the preceding description.

The steps of FIG. **10***c* are also integrated in the general program mentioned earlier; there are undertaken in succession a first phase I (preparation of the intervention), then a second phase II, (prior to the actual intervention, the patient is placed in a condition for intervention, the reference structure SR being tied to the second reference frame R_2), then a third phase III (intervention) and finally a post-intervention phase IV.

With a view to preparing the intervention, the system requests the surgeon (step **5000**) to choose the elementary structures of interest (for example bones of the skull, ventricles, vascular regions, the tumor to be explored or treated, and the images of the marks constituting in the first reference frame the representation RSR).

The choice of the elementary structures of interest is made on the display of the tomographic images, for example, called up from the digitized file **10**.

The system next performs, at step **5001**, a modeling of the structures of interest, as described earlier. Then, the nonhomogeneous structure having been thus constituted as a three-dimensional model RSNH displayed on the screen, the intervening surgeon is then led to perform a simulation by three-dimensional imaging, at step **5002**, with a view to defining the intervention path of the tool **50**.

During phase II the patient being placed in a condition for intervention and his head and the reference structure SR being tied to the second reference frame R_2, the surgeon performs at step **5003** a search for the position of the marks **M1** to **M4** constituting base points of the reference structure in the second reference frame R_2, and then during a step **5004**, performs a search for the position of the sighting systems, visualizing member OV, or of the tools and intervention instruments **50**, still in the second reference frame R_2, so as, if appropriate, to align these implements with respect to R_2.

The system then performs the validation of the intervention/patient spaces and representation by three-dimensional imaging in order to determine next the common origin of intervention ORI. In other words, the matrix reference frame transfer described above is supplemented with the necessary origin translations (origins **01** and **02** aligned on ORI).

This operation is performed as described earlier.

Phase III corresponds to the intervention, during which the system effects at step **5006** a permanent coupling in real time between the direction of aim of the active member **50**, and/or of the direction of aim of the sighting member OV (and if appropriate of the laser beam), with the direction of aim (of observation) simulated by three-dimensional imaging on the display means **1**, and vice versa.

In the following step **5007**, the coupling is effected of the movements and motions of the intervention instrument with their movements simulated by three-dimensional imaging, with automatic or manual conduct of the intervention.

As noted at **5008**, the surgeon can be supplied with a permanent display of the original two-dimensional sectional images in planes specified with respect to the origin ORI and to the direction of intervention. Such a display enables the surgeon at any time to follow the progress of the intervention in real time and to be assured that the intervention is proceeding in accordance with the simulated intervention. In phase IV which is executed after the intervention, the system effects a saving of the data acquired during the intervention, this saving making it possible subsequently to effect a comparison in real time or deferred in the event of successive interventions on the same patient.

Furthermore, the saved data make it possible to effect a playback of the operations carried out with the option of detailing and supplementing the regions traversed by the active member **50**.

Thus, a particularly powerful interactive system for local intervention has been described.

Thus, the system which is the subject of the present invention makes it possible to represent a model containing only the essential structures of the nonhomogeneous structure, this facilitating the work of preparation and of monitoring of the intervention by the surgeon.

Moreover, the system, by virtue of the algorithms used and in particular by minimizing the distortion between the real base points and their images in the **2**D sections or the maps, makes it possible to establish a two-way coupling between the real world and the computer world through which the transfer errors are minimized, making possible concrete exploitation of the imaging data in order to steer the intervention tool.

To summarize, the system makes possible an ineractive [sic] medical usage not only to create a three-dimensional model of the nonhomogeneous structure but also to permit a marking in real time with respect to the internal structures and to guide the surgeon in the intervention phase.

More generally, the invention makes it possible to end up with a coherent system in respect of:

- the two-dimensional imaging data (scanner sections, maps, etc.)
- the three-dimensional data base;
- the data supplied by the marker means **3** in the reference frame R_2;
- the coordinate data for the sighting systems and intervention tools;
- the real world of the patient on the operating table.

Accordingly, the options offered by the system are, in a non-limiting manner, the following:

- the tools and of [sic] their position can be represented on the screen;
- the position of a point on the screen can be materialized on the patient for example with the aid of the laser emission device EL;
- the orientation and the path of a tool such as a needle can be represented on the screen and materialized on the patient optically (laser emission) or mechanically (positioning of the guide-arm in which the tool is guided in translation):
- an image of the patient, yielded for example by a system for taking pictures if appropriate in relief, can be superimposed on the three-dimensional representation modeled on the screen; thus, any change in the soft external parts of the patient can be visualized as compared with the capture by the scanner;
- it being possible for the surgeon's field of view given by a sighting member (such as a surgical microscope) to be referenced with respect to R_2, the direction of visualization of the model on the screen can be made identical to the real sight by the sighting member;
- finally, the three-dimensional images, normally displayed on the screen in the preceding description, may as a variant be introduced into the surgeon's microscope so as to obtain the superposition of the real image and the representation of the model.

We claim:

1. An interactive system for local intervention inside a region of a non-homogeneous structure to which is connected a reference structure containing a plurality of base points, the interactive system comprising:

- means for dynamically displaying a three-dimensional image of a representation of the non-homogeneous structure and of the reference structure connected to the non-homogeneous structure, wherein the three-dimensional image also includes a plurality of images of the plurality of base points;
- means for determining a set of coordinates of the plurality of images of the plurality of base points in a first reference frame;
- means for fixing a position of the non-homogeneous structure and of the reference structure with respect to a second reference frame;
- means for determining a set of coordinates of the plurality of base points in the second reference frame;
- means of intervention comprising an active member whose position is determined with respect to the second reference frame;
- means for generating a plurality of reference frame translation tools for translating a plurality of reference frames from the first reference frame to the second reference frame and vice versa, based on the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and of the set of coordinates of the plurality of base points in the second reference frame, in such a way as to reduce to a minimum at least one of a set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, expressed in the first reference frame using the plurality of reference frame translation tools;
- means for defining, with respect to the first reference frame, a simulated origin of intervention and a simulated direction of intervention; and,
- means for transferring the plurality of reference frames using the plurality of reference frame translation tools to establish a bidirectional coupling between the simulated origin of intervention and the simulated direction of intervention and the position of the active member.

2. The interactive system according to claim **1**, wherein the plurality of reference frame translation tools comprise:

- means for creating a matrix (M) for transferring between the first reference frame and a first intermediate reference frame based on a set of coordinates of a set of three images of a set of three base points of the reference structure;
- means for creating a matrix (N) for transferring between the second reference frame and a second intermediate

reference frame based on the set of coordinates of the set of three images of the set of three base points of the reference structure; and,

means for validating matrix (M) and matrix (N) based on the set of three base points and the set of three images, such that at least one deviation between an expression for at least one additional base point in the second intermediate reference frame and an expression for at least one image point of the additional base point in the first intermediate reference frame is reduced to a minimum.

3. The interactive system according to plurality of claim 2, wherein the means for transferring the reference frames using the plurality of reference frame translation tools further comprises:

a first transfer sub-module for transferring a set of representation/non-homogeneous structure coordinates, and

a second transfer sub-module for transferring a set of non-homogeneous structure/representation coordinates.

4. The interactive system according to claim 3, wherein the first transfer sub-module comprises:

means for acquiring a set of coordinates (XM, YM, ZM), expressed in the first reference frame, of a point of the representation of the non-homogeneous structure to be transferred, by selection on the representation;

means for calculating a set of corresponding coordinates (XP, YP, ZP), expressed in the second reference frame, on the non-homogeneous structure through a transformation:

$\{YP,YP, ZP\}=M*N^{-1} *\{XM,YM,ZM\}$ where $M * N^{-1}$ represents a product of the matrix (M) and an inverse of the matrix (N), and

means for processing, with the aid of the corresponding coordinates (YP, YP, ZP), to display a corresponding point on a surface of the non-homogeneous structure and to secure the intervention.

5. The interactive system according to claim 3, wherein the second transfer sub-module comprises:

means for acquiring a set of coordinates (XP, YP, ZP), expressed in the second reference frame, of a point of the non-homogeneous structure to be transferred;

means for calculating a set of corresponding coordinates (XM YM, ZM), expressed in the first reference frame, of the representation through a transformation:

$\{YM, YM, ZM\}=N*M^{-1} *\{XP,ZP,ZP\}$ where $N*M^{-1}$ represents the product of the matrix (N) and an inverse of the matrix (M); and,

means for displaying the representation using the set of corresponding coordinates (YM, YM, ZM).

6. The interactive system according to claim 1, wherein the means for generating the plurality of reference frame translation tools also generate, in association with the reference frame translation tools, tools for taking into account a residual uncertainty which is based on the set of deviations between the set of coordinates of the plurality of images of the plurality of base points in the first reference frame and the set of coordinates of the base points, the tools for taking into account the residual uncertainty usable for displaying a set of contours in the representation whilst taking into account the residual uncertainties.

7. The interactive system according to claim 1, wherein the means of dynamic displaying the three-dimensional image comprises:

a file containing digitized data from a set of two-dimensional images constituted by successive non-invasive tomographic sections of the non-homogeneous structure;

means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images; and

a high-resolution display screen.

8. The interactive system according to claim 7, wherein the means for calculating and reconstructing the three-dimensional image from the set of two-dimensional images comprises a program consisting of computer-aided design type software.

9. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points in the second reference frame comprises a three-dimensional probe equipped with a tactile tip for delivering a set of coordinates of the tactile tip in the said second reference frame.

10. The interactive system according to claim 1, wherein the means for determining the set of coordinates of the plurality of base points is the second reference frame comprises at least one of a set of optical sensors and a set of electromagnetic sensors.

11. The interactive system according to claim 1, wherein a portion of the set of the plurality of base points of the reference structure comprises a plurality of marks positioned on a lateral surface of the non-homogeneous structure.

12. The interactive system according to claim 11, wherein the plurality of marks are four in number and are distributed over the lateral surface so as to define a substantially symmetrical tetrahedron.

13. The interactive system according to claim 1, wherein the means of intervention comprises:

a guide arm to secure intervention in the region of the non-homogeneous structure, the guide arm having a position marked with respect to the second reference frame; and,

an active intervention member whose position is marked with respect to the second reference frame.

14. The interactive system according to claim 13, wherein the active intervention member is removable and selected from the group consisting of:

tools for trephining;

needles and implants;

laser and radioisotope emission heads; and, sighting and viewing systems.

15. The interactive system according to claim 1, wherein the means for transferring the plurality of reference frames establishes a coupling between a direction of visualization of the representation of the non-homogeneous structure on the display means and a direction of observation of the non-homogeneous structure and of the reference structure by the active intervention member.

16. The interactive system according to claim 15, further comprising:

a first module for visualizing a representation in a direction given by two points;

a second module for visualizing a representation in a direction given by an angle of elevation and an angle of azimuth.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.: 5,868,675

DATED: February 9, 1999

INVENTOR(S): Henrion et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Title, item [54], delete "NONHUMOGENEOUS STRUCTURE" and insert — NON-HOMOGENEOUS STRUCTURE --.

At item [22], the PCT filing date, delete "May 10, 1990" and insert — October 5, 1990 --.

Signed and Sealed this

Eighth Day of May, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office

English	French
SUPPLEMENTAL DECLARATION FOR REISSUE PATENT APPLICATION TO CORRECT "ERRORS" STATEMENT (37 CFR 1.175)	DÉCLARATON SUPPLÉMENTAIRE POUR REDÉLIVRANCE D'UNE DEMNADE DE BREVET POUR CORRIGER DES « ERREURS » (37 CFR 1.175)
Attorney Docket: 5074A-000013/REA First Named Inventor: Jean Francois Uhl Application Number: 09/784,829 Filing Date: February 8, 2001 Art Unit: 3737 Examiner Name: Ruth S. Smith	Numéro de registre: 5074A-000013/REA Nom du premier inventeur: Jean Francois Uhl Numéro de l'application: 09/784,829 Date de dépôt: 8 février 2001 Unité d'art : 3737 Nom de l'examinateur: Ruth S. Smith
I/We hereby declare that: **Every error in the patent which was corrected in the present reissue application, and which is not covered by the prior oath(s) and/or declaration(s) submitted in this application, arose without any deceptive intention on the part of the applicant.** **WARNING:** **Petitioner/applicant is cautioned to avoid submitting personal information in documents files in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO.** **Petitioner/application is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.** **I/We hereby declare that all statements made herein of my/our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.**	**Je(nous) déclare(ons) que :** **Toute erreur dans le brevet qui a été corrigée dans cette demande de redélivrance et qui n'est pas couverte par le présent serment ou déclaration soumis à cette demande, s'est produite sans intention de tromper de la part de l'appliquant.** **AVERTISSEMENT :** **Le requérant / demandeur est mis en garde contre la soumission de renseignements personnels dans les documents déposés dans une demande de brevet qui peuvent aider à l'usurpation d'identité. Les renseignements personnels tels que numéros de sécurité sociale, numéros de compte bancaire, ou numéros de carte de crédit (autre qu'un chèque ou un formulaire d'autorisation de carte de crédit PTO-2038 dans le but de faire un paiement) ne sont jamais requis par l'USPTO (Bureau des brevets des États-Unis) pour appuyer une pétition ou une demande. Si ce type de renseignements personnels est inclus dans les documents déposés à l'USPTO, les demandeurs / requérants devraient envisager de les enlever des documents avant de les soumettre à l'USPTO.** **Le requérant / demandeur est informé que le dossier de demande de brevet est à la disposition du public après la publication de la demande (sauf si une demande de non-publication en conformité avec 37 CFR 1.213 (a) a été faite dans cette demande) ou après la délivrance d'un brevet. En outre, le dossier d'une demande abandonnée peut également être mis à la disposition du public si la demande est référencée dans une application publiée ou un brevet délivré (voir 37 CFR 1.14). Les chèques et formulaires d'autorisation de carte de crédit PTO-2038 soumis pour fins de paiement ne sont pas conservés dans le dossier de demande et ne sont donc pas accessibles au public.** **Je / Nous déclarons que toutes les déclarations faites selon ma/notre connaissance dans ce document sont véridiques et que toutes les déclarations faites sur des informations et croyances sont considérées comme vraies. De plus, ces déclarations ont été faites en sachant que toute fausse déclaration volontaire est passible d'une amende ou d'une peine d'emprisonnement, ou les deux, en vertu de la loi 18 USC 1001 et que de telles déclarations risquent de compromettre la validité de la demande ou d'un brevet délivré à partir de celle-ci.**
Name of First Inventor: Jean Francois Uhl Inventor's Signature ________________ Date ________________	Nom du premier inventeur: Jean Francois Uhl Signature de l'inventeur ________________ Date ____________________
Name of Second Inventor: Joel Henrion Inventor's Signature________________ Date________________	Nom du deuxième inventeur : Joel Henrion Signature de l'inventeur ________________ Date ____________________
Name of Third Inventor: Michel Scriban Inventor's Signature ________________ Date ________________	Nom du troisième inventeur : Michel Scriban Signature de l'inventeur ________________ Date ____________________
Name of Fourth Inventor: Jean-Baptiste Thiebaut Inventor's Signature ________________ Date________________	Nom du quatrième inventeur : Jean-Baptiste Thiebaut Signature de l'inventeur ________________ Date ____________________

ATTACHMENT O

Taylor, Michael

From: Sophie PONCET <sophie.ccgl@wanadoo.fr>
Sent: Tuesday, November 29, 2011 6:07 AM
To: Taylor, Michael
Cc: GRANGE Maxime
Subject: Re: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]

Importance: High

Cher Confrère,

J'ai bien reçu vos deux derniers envois concernant le dossier en référence.

Je maintiens les termes de ma correspondance du 15 novembre 2011.

En effet, les spécialistes français que je représente ne peuvent en aucun cas étudier, de manière gracieuse, l'intégralité des pièces que vous leur avez transmises.

Il n'est pas non plus possible qu'ils donnent leur signature sur des documents qui n'auraient pas pu être préalablement étudiés.

Je reste donc dans l'attente, à nouveau, de connaître la position définitive que prendra votre cliente, la société MEDTRONIC.

Vous remerciant de me fixer,

Je vous souhaite bonne réception de la présente, et vous prie de croire, en mes sentiments les plus dévoués.

Maxime GRANGE
ACCESS AVOCATS
63 avenue de Saxe - 69003 LYON
T 04 72 84 99 60
F 04 72 84 99 69

----- Original Message -----
From: Taylor, Michael
To: 'Sophie PONCET'
Cc: 'GRANGE Maxime' ; Warner, Rick ; Neal, Patrick ; Hall, Stephanie
Sent: Wednesday, November 23, 2011 3:21 PM
Subject: RE: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]

Cher GRANGE,

My email of yesterday appears to have been missing our letter. I apologize for this oversight. If you received our letter dated November 22, 2011 in yesterday's email, this email is a duplicate.

Best Regards,

Michael Taylor

HARNESS DICKEY **Michael L. Taylor** | Patent Attorney
O | 248.641.1600 **F** | 248.641.0270 **D** | 248.641.1289
IP Causes Worldwide

From: Taylor, Michael
Sent: Tuesday, November 22, 2011 11:57 AM
To: 'Sophie PONCET'
Cc: GRANGE Maxime; Warner, Rick; Neal, Patrick; Hall, Stephanie
Subject: RE: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]

Cher GRANGE,

We understand that you are an attorney for all of Michel Scriban, Joel Henrion, Jean Francois UHL, and Jean-Baptiste Thiebaut.

Please see our attached letter dated November 22, 2011, which refers to our previous correspondence, also attached.

Best Regards,

Michael Taylor

HARNESS DICKEY **Michael L. Taylor** | Patent Attorney
O | 248.641.1600 **F** | 248.641.0270 **D** | 248.641.1289
IP Causes Worldwide

From: Sophie PONCET [mailto:sophie.ccgl@wanadoo.fr]
Sent: Tuesday, November 15, 2011 9:28 AM
To: Taylor, Michael
Cc: GRANGE Maxime
Subject: MEDTRONIC
Importance: High

Cher Monsieur,

Maître GRANGE, avocat au barreau de Lyon, répond à vos correspondances échangées notamment avec Michel SCRIBAN concernant le dossier en référence.

Nous restons dans l'attente de votre réponse.

Vous en remerciant par avance,

Nous vous adressons nos sentiments les plus dévoués.

Maxime GRANGE

ACCESS AVOCATS

63 avenue de Saxe - 69003 LYON
T 04 72 84 99 60
F 04 72 84 99 69

ATTACHMENT P

Taylor, Michael

From: Global Language links <globallanguagelinks@yahoo.com>
Sent: Tuesday, November 29, 2011 11:00 AM
To: Taylor, Michael
Cc: kwallace@globlanglinks.com; Laura
Subject: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]
Attachments: image001.gif

Hi Micheal, Here it is. [redacted] Thank you and have a wonderful day!!

Dear Colleague,

I received your last two correspondences regarding the file in reference.

I uphold what I stated in my correspondence of November 15th, 2011.

Indeed, the French experts that I represent cannot, in any way, study gracefully all the documents you have provided them with.

Moreover, it is not possible for them to sign documents that they did not have the chance to previously study.

Again, I am waiting for the decision that your client, Medtronic, will take.

Thank you for letting me know this decision and settling in this matter,

I wish you good reception of this letter. Sincerely,

----- Forwarded Message -----
From: Kimberly Wallace <kwallace@globlanglinks.com>
To: gll <globallanguagelinks@yahoo.com>
Sent: Tuesday, November 29, 2011 10:21 AM
Subject: Fwd: FW: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]

Sent from my MetroPCS Android Device

-------- Original Message --------
Subject: FW: MEDTRONIC (5074A-000013/REA) [HDP-Troy_Legal.FID2452556]
From: "Taylor, Michael" <mltaylor@HDP.com>
To: "'KWallace@GlobLangLinks.com'" <KWallace@GlobLangLinks.com>
CC:

Dear Kim,

Is there a chance I can get the below translated to English today?

Thanks, Michael

----- Cher Confrère,

J'ai bien reçu vos deux derniers envois concernant le dossier en référence.

Je maintiens les termes de ma correspondance du 15 novembre 2011.

En effet, les spécialistes français que je représente ne peuvent en aucun cas étudier, de manière gracieuse, l'intégralité des pièces que vous leur avez transmises.

Il n'est pas non plus possible qu'ils donnent leur signature sur des documents qui n'auraient pas pu être préalablement étudiés.

Je reste donc dans l'attente, à nouveau, de connaître la position définitive que prendra votre cliente, la société MEDTRONIC.

Vous remerciant de me fixer,

Je vous souhaite bonne réception de la présente, et vous prie de croire, en mes sentiments les plus dévoués.

[Description: HDP]<http://www.hdp.com/>

Michael L. Taylor | Patent Attorney
O | 248.641.1600 F | 248.641.0270 D | 248.641.1289
IP Causes Worldwide